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Olsson et al.

(10) **Patent No.: US 11,209,115 B2**
(45) **Date of Patent: Dec. 28, 2021**

(54) **PIPE INSPECTION AND/OR MAPPING CAMERA HEADS, SYSTEMS, AND METHODS**

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(73) Assignee: **SEESCAN, INC.**, San Diego, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **16/687,057**

(22) Filed: **Nov. 18, 2019**

(65) **Prior Publication Data**

US 2020/0173602 A1 Jun. 4, 2020

Related U.S. Application Data

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(51) **Int. Cl.**
F16L 55/48 (2006.01)
F16L 55/46 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***F16L 55/48*** (2013.01); ***F16L 55/46*** (2013.01); ***G01C 21/16*** (2013.01); ***G01V 3/12*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC H04N 2005/2255; H04N 5/2253; H04N 5/2256; H04N 5/2355; H04N 7/183;
(Continued)

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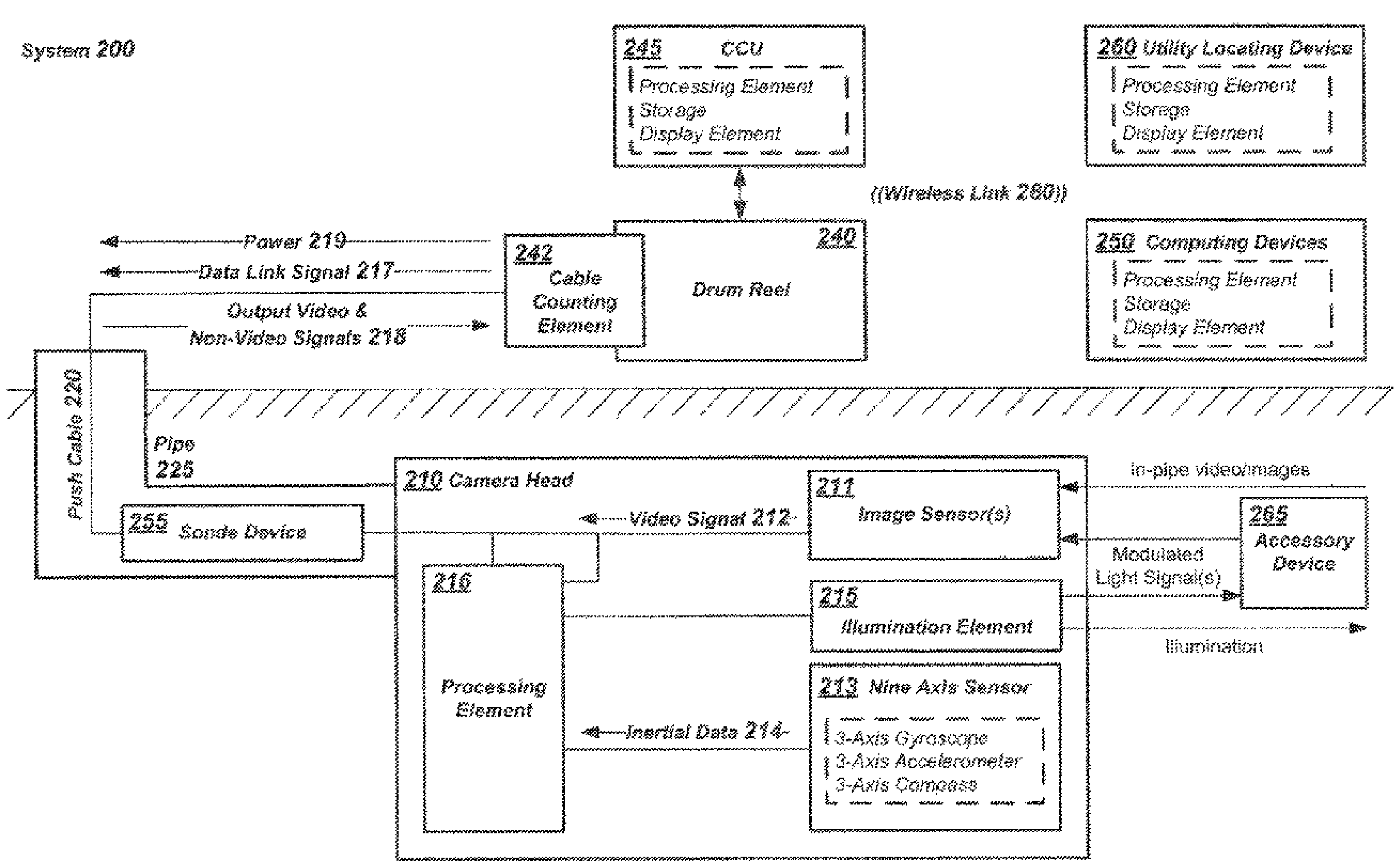
Primary Examiner — Paulos M Natnael

(74) *Attorney, Agent, or Firm* — Michael J. Pennington, Esq.; Steven C. Tietsworth, Esq.

(57) **ABSTRACT**

Camera heads and associated systems, methods, and devices for inspecting and/or mapping pipes or cavities are disclosed. A camera head may be coupled to a push-cable and may include one or more image sensors to capture images and/or videos from interior of the pipe or cavity. One or more multi-axis sensors may be disposed in the camera head to sense data corresponding to movement of the camera head within the pipe or cavity. The images and/or videos captured by the image sensors may be used in conjunction with the data sensed by the multi-axis sensors to generate information pertaining to the pipe or cavity may be generated.

22 Claims, 30 Drawing Sheets



(51) **Int. Cl.**

G01C 21/16	(2006.01)
G01V 3/12	(2006.01)
H04N 5/225	(2006.01)
H04N 5/235	(2006.01)
H04N 7/18	(2006.01)
F16L 101/30	(2006.01)

(52) **U.S. Cl.**
CPC ***H04N 5/2253*** (2013.01); ***H04N 5/2256*** (2013.01); ***H04N 5/2355*** (2013.01); ***H04N 7/183*** (2013.01); *F16L 2101/30* (2013.01); *H04N 2005/2255* (2013.01)

(58) **Field of Classification Search**
CPC G03B 37/005; F16L 55/48; F16L 55/46; F16L 2101/30; G01C 21/16; G01V 3/12; G06F 11/0778; G06F 11/3466; G06F 11/1407; G06F 11/0709; G06F 11/0715; G06F 11/1471
See application file for complete search history.

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2020/0088653	A1*	3/2020	Martin	G01N 21/954

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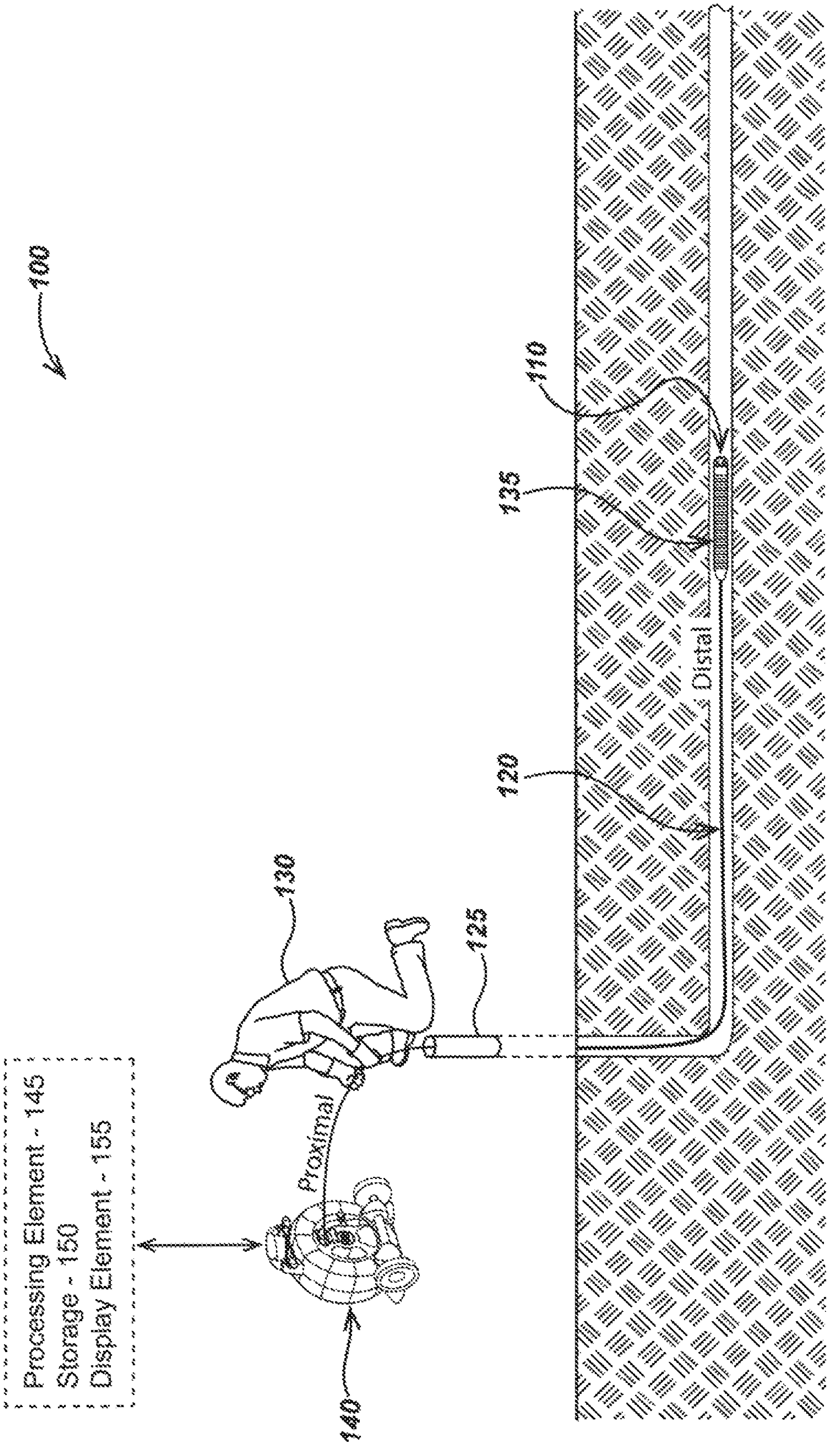
100
110
135
Distal
120
130
125
Proximal
Processing Element - 145
Storage - 150
Display Element - 155
140

FIG. 1A

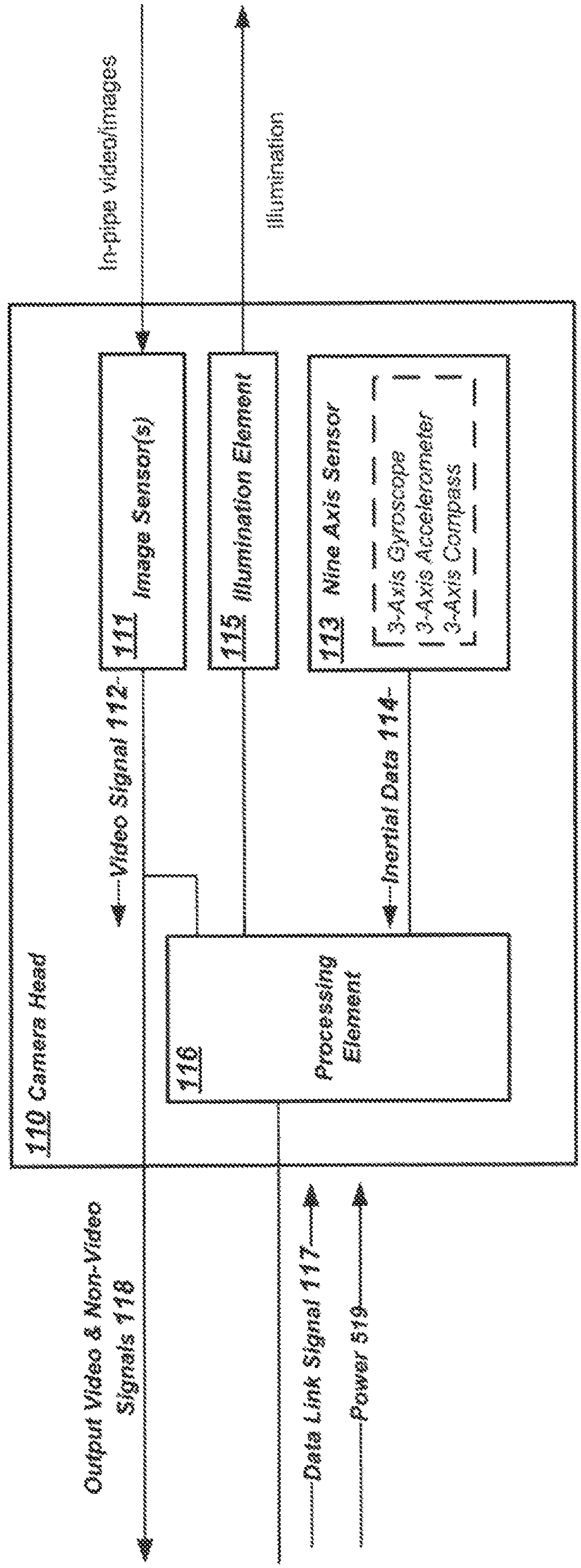
In-pipe video/images
Illumination
110 Camera Head
111 Image Sensor(s)
115 Illumination Element
113 Nine Axis Sensor
3-Axis Gyroscope
3-Axis Accelerometer
3-Axis Compass
Video Signal 112
Inertial Data 114
116 Processing Element
Output Video & Non-Video Signals 118
Data Link Signal 117
Power 519

FIG. 1B

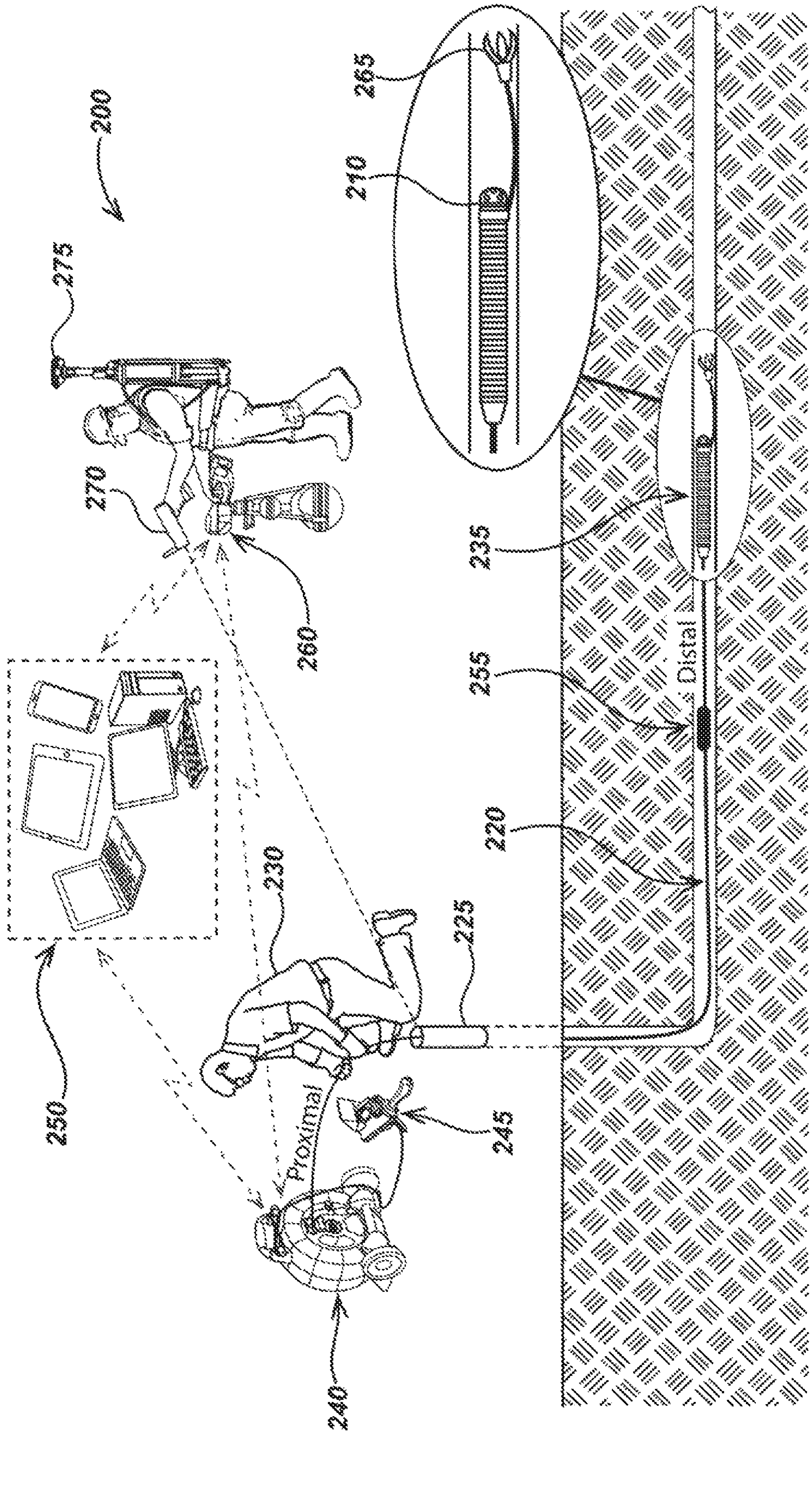
200
275
270
260
265
210
235
255
Distal
220
225
230
250
245
Proximal
240

FIG. 2A

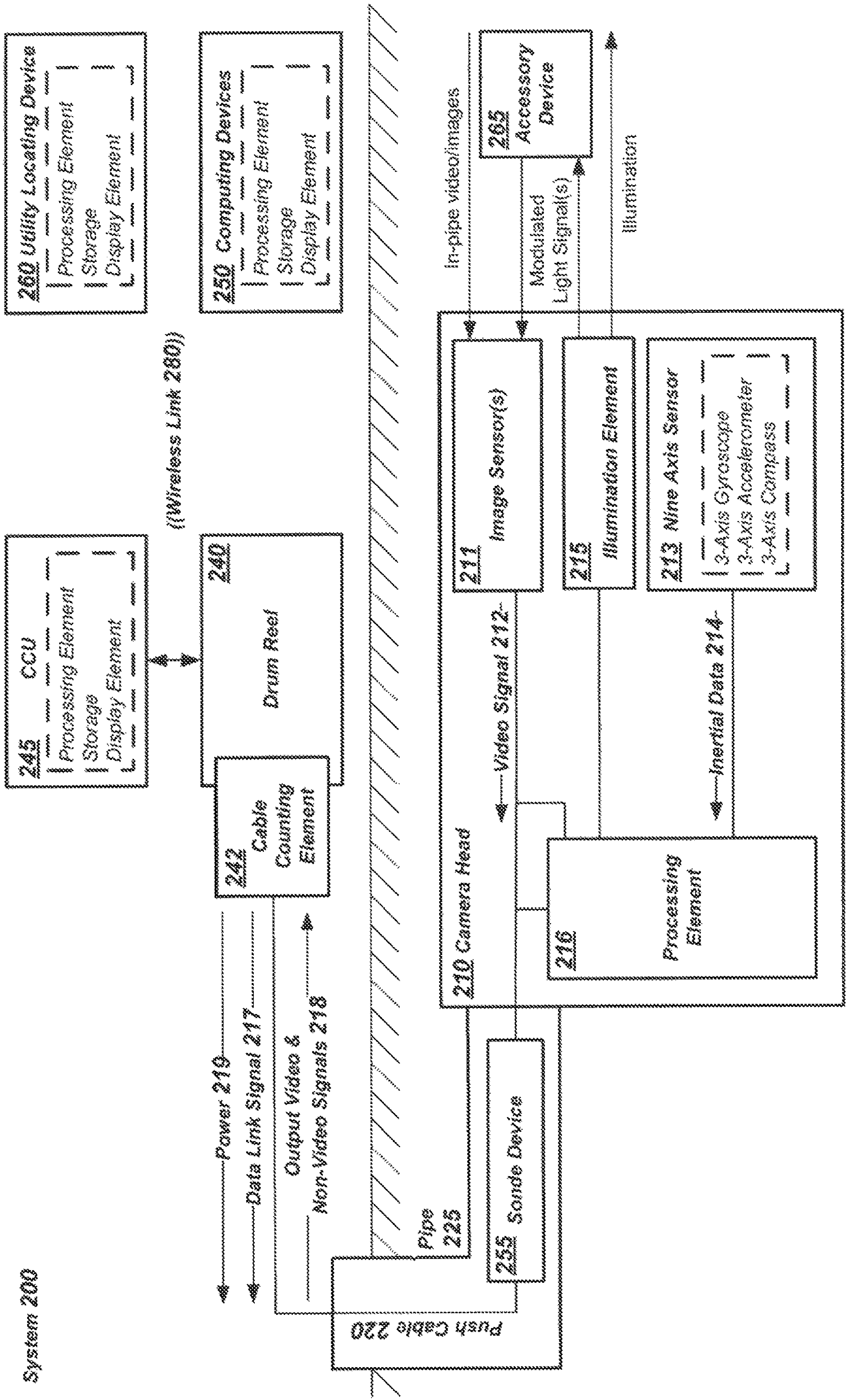
System 200
260 Utility Locating Device
Processing Element
Storage
Display Element
250 Computing Devices
Processing Element
Storage
Display Element
245 CCU
Processing Element
Storage
Display Element
(Wireless Link 280)
240
Drum Reel
242 Cable Counting Element
Power 219
Data Link Signal 217
Output Video & Non-Video Signals 218
Pipe 225
Push Cable 220
255 Sonde Device
210 Camera Head
211 Image Sensor(s)
215 Illumination Element
213 Nine Axis Sensor
3-Axis Gyroscope
3-Axis Accelerometer
3-Axis Compass
216 Processing Element
Video Signal 212
Inertial Data 214
265 Accessory Device
In-pipe video/images
Modulated Light Signal(s)
Illumination

FIG. 2B

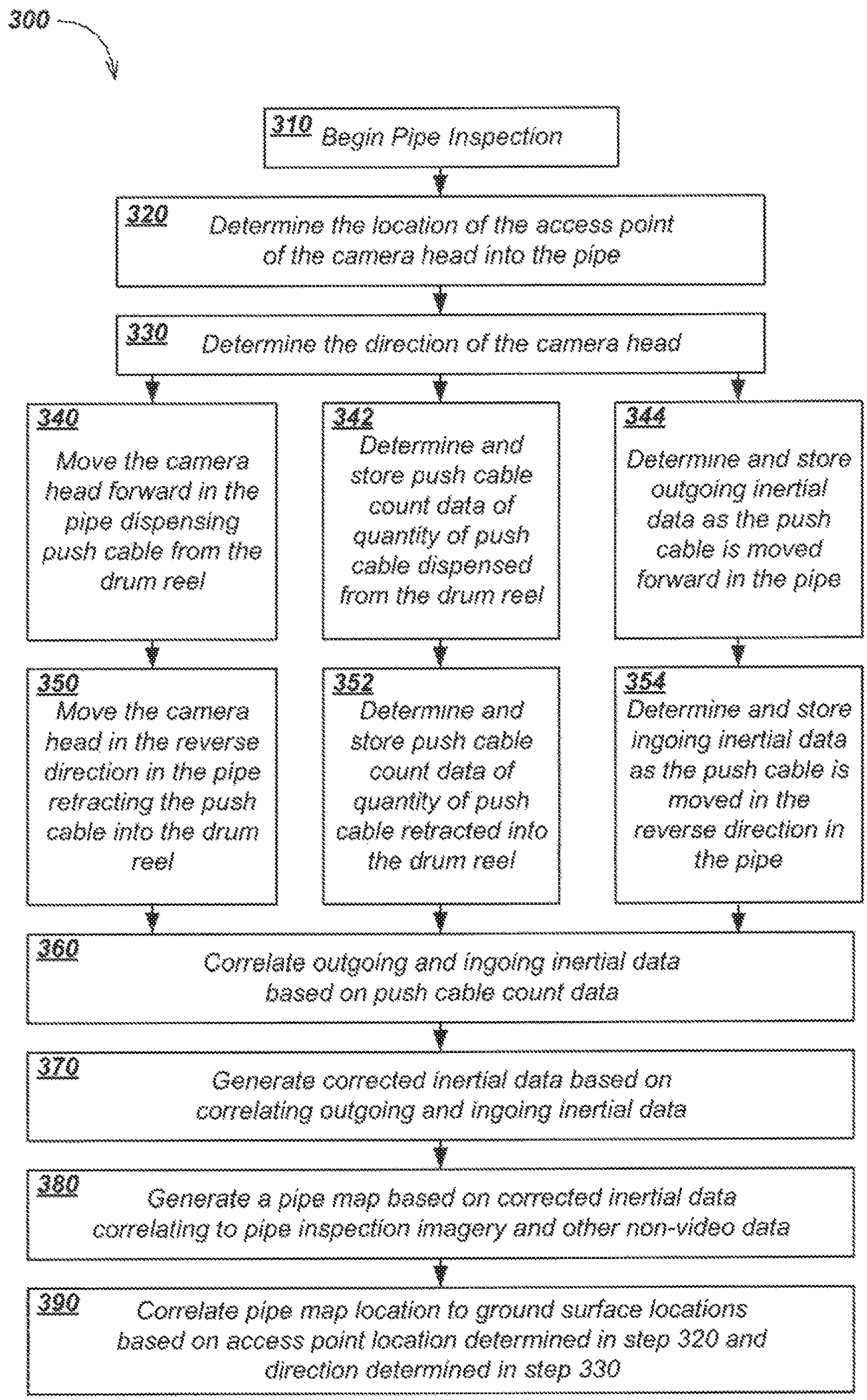
300
310 Begin Pipe Inspection
320 Determine the location of the access point of the camera head into the pipe
330 Determine the direction of the camera head
340 Move the camera head forward in the pipe dispensing push cable from the drum reel
342 Determine and store push cable count data of quantity of push cable dispensed from the drum reel
344 Determine and store outgoing inertial data as the push cable is moved forward in the pipe
350 Move the camera head in the reverse direction in the pipe retracting the push cable into the drum reel
352 Determine and store push cable count data of quantity of push cable retracted into the drum reel
354 Determine and store ingoing inertial data as the push cable is moved in the reverse direction in the pipe
360 Correlate outgoing and ingoing inertial data based on push cable count data
370 Generate corrected inertial data based on correlating outgoing and ingoing inertial data
380 Generate a pipe map based on corrected inertial data correlating to pipe inspection imagery and other non-video data
390 Correlate pipe map location to ground surface locations based on access point location determined in step 320 and direction determined in step 330

FIG. 3

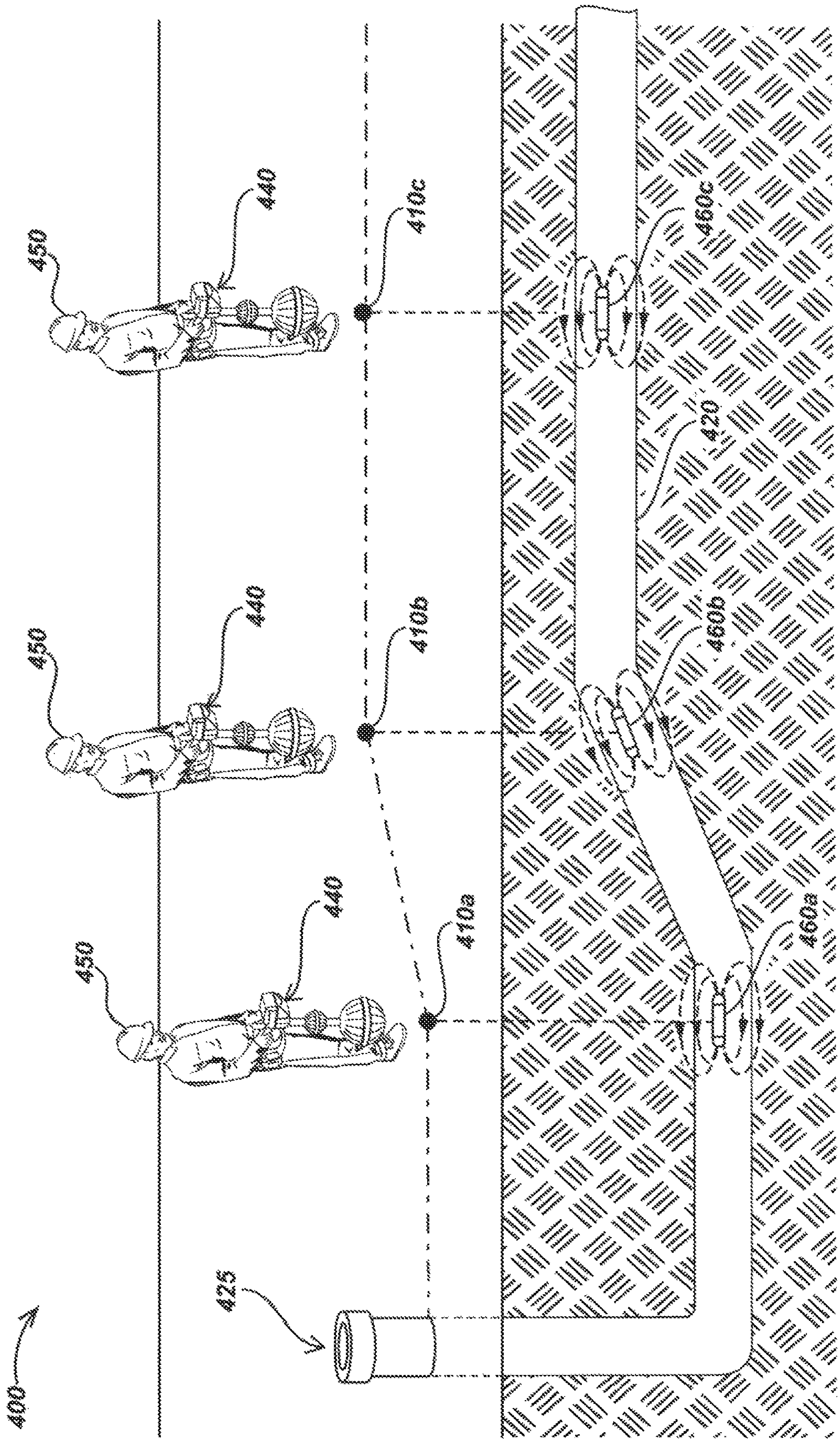

FIG. 4

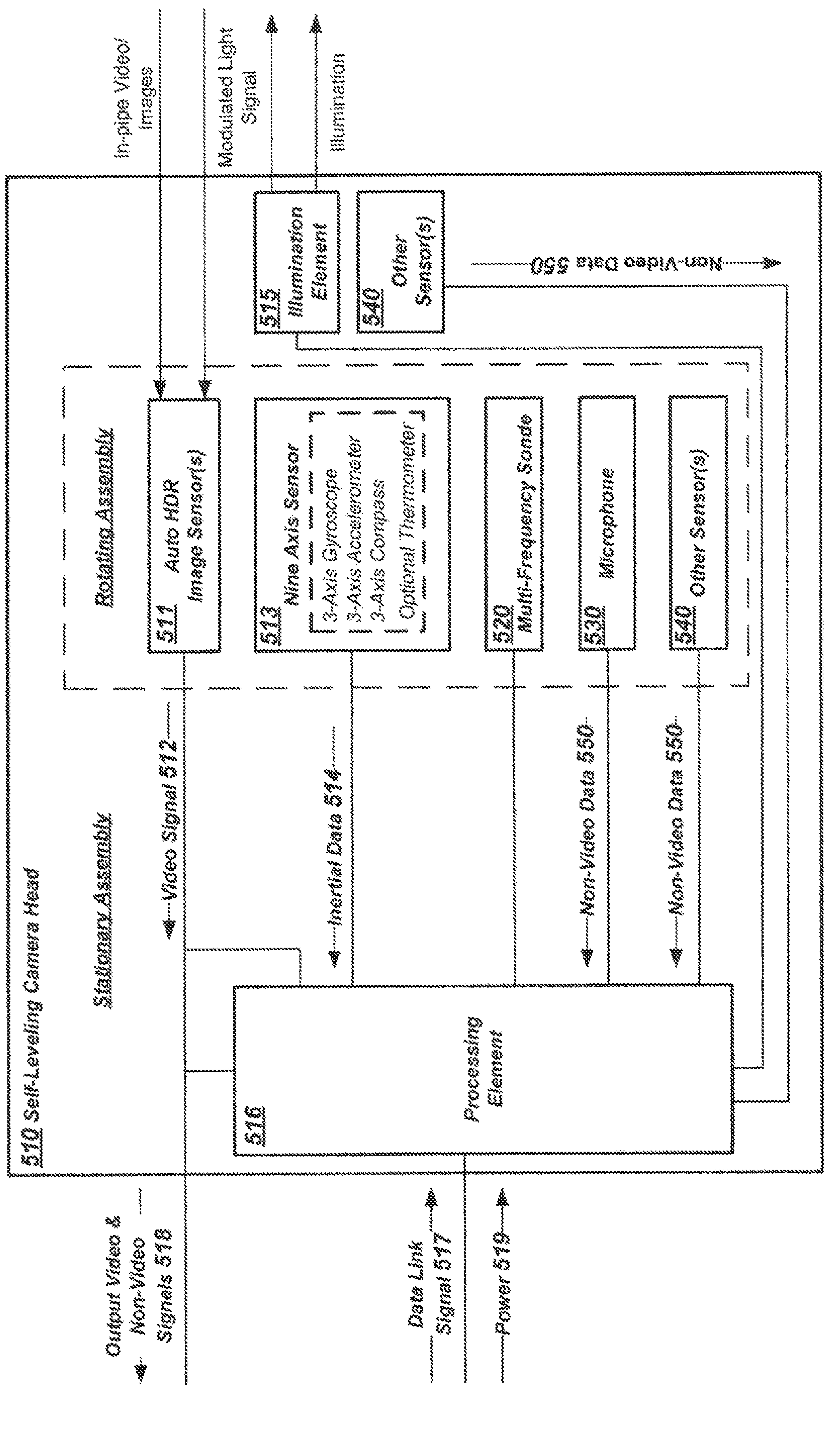
In-pipe Video/ Images
Modulated Light Signal
Illumination
510 Self-Leveling Camera Head
515 Illumination Element
540 Other Sensor(s)
Non-Video Data 550
Rotating Assembly
511 Auto HDR Image Sensor(s)
513 Nine Axis Sensor
3-Axis Gyroscope
3-Axis Accelerometer
3-Axis Compass
Optional Thermometer
520 Multi-Frequency Sonde
530 Microphone
540 Other Sensor(s)
Stationary Assembly
Video Signal 512
Inertial Data 514
Non-Video Data 550
Non-Video Data 550
516 Processing Element
Output Video & Non-Video Signals 518
Data Link Signal 517
Power 519

FIG. 5

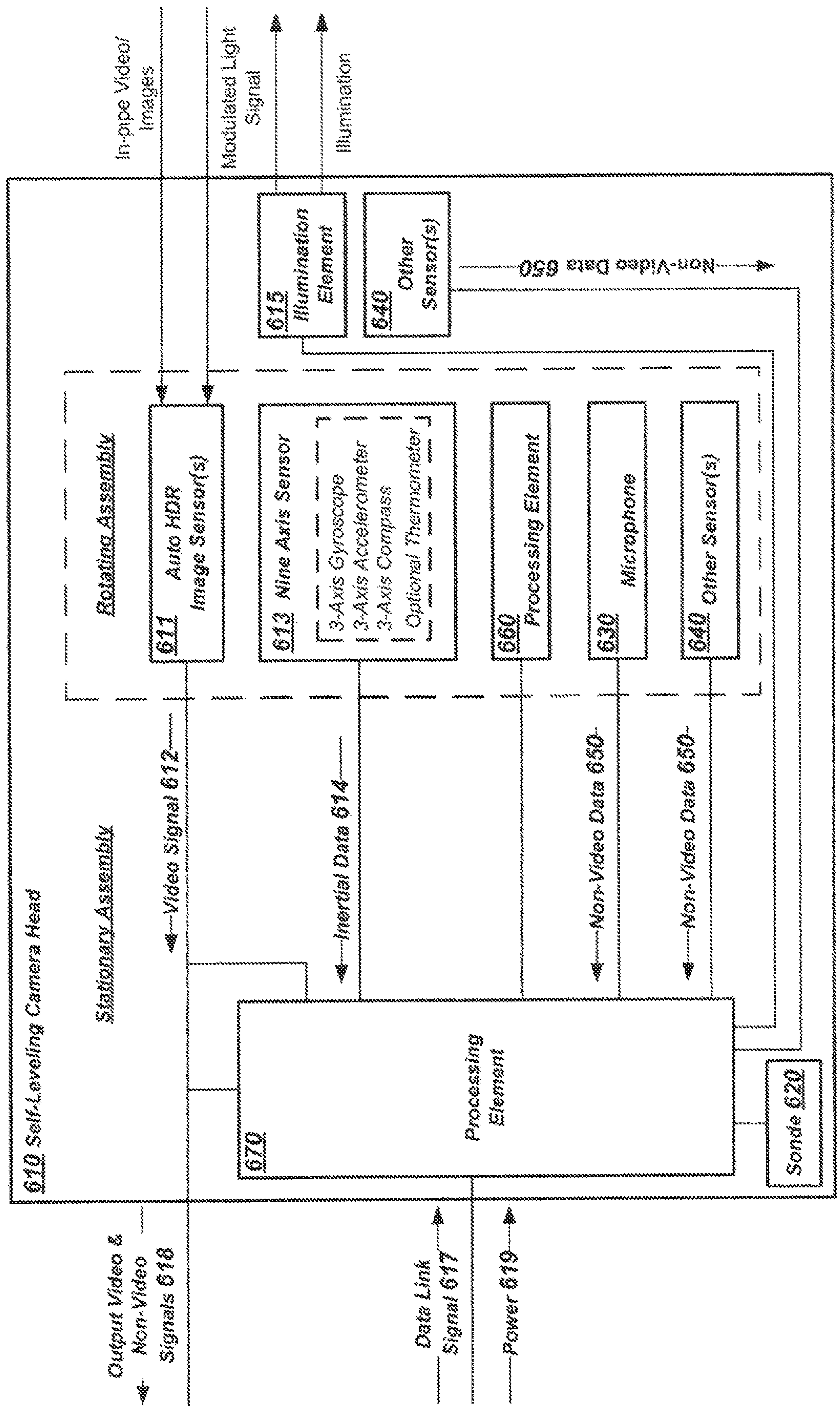
610 Self-Leveling Camera Head
Stationary Assembly
Rotating Assembly
611 Auto HDR Image Sensor(s)
613 Nine Axis Sensor
3-Axis Gyroscope
3-Axis Accelerometer
3-Axis Compass
Optional Thermometer
660 Processing Element
630 Microphone
640 Other Sensor(s)
615 Illumination Element
640 Other Sensor(s)
Non-Video Data 650
In-pipe Video/ Images
Modulated Light Signal
Illumination
Video Signal 612
Inertial Data 614
Non-Video Data 650
Non-Video Data 650
670 Processing Element
Sonde 620
Output Video & Non-Video Signals 618
Data Link Signal 617
Power 619

FIG. 6

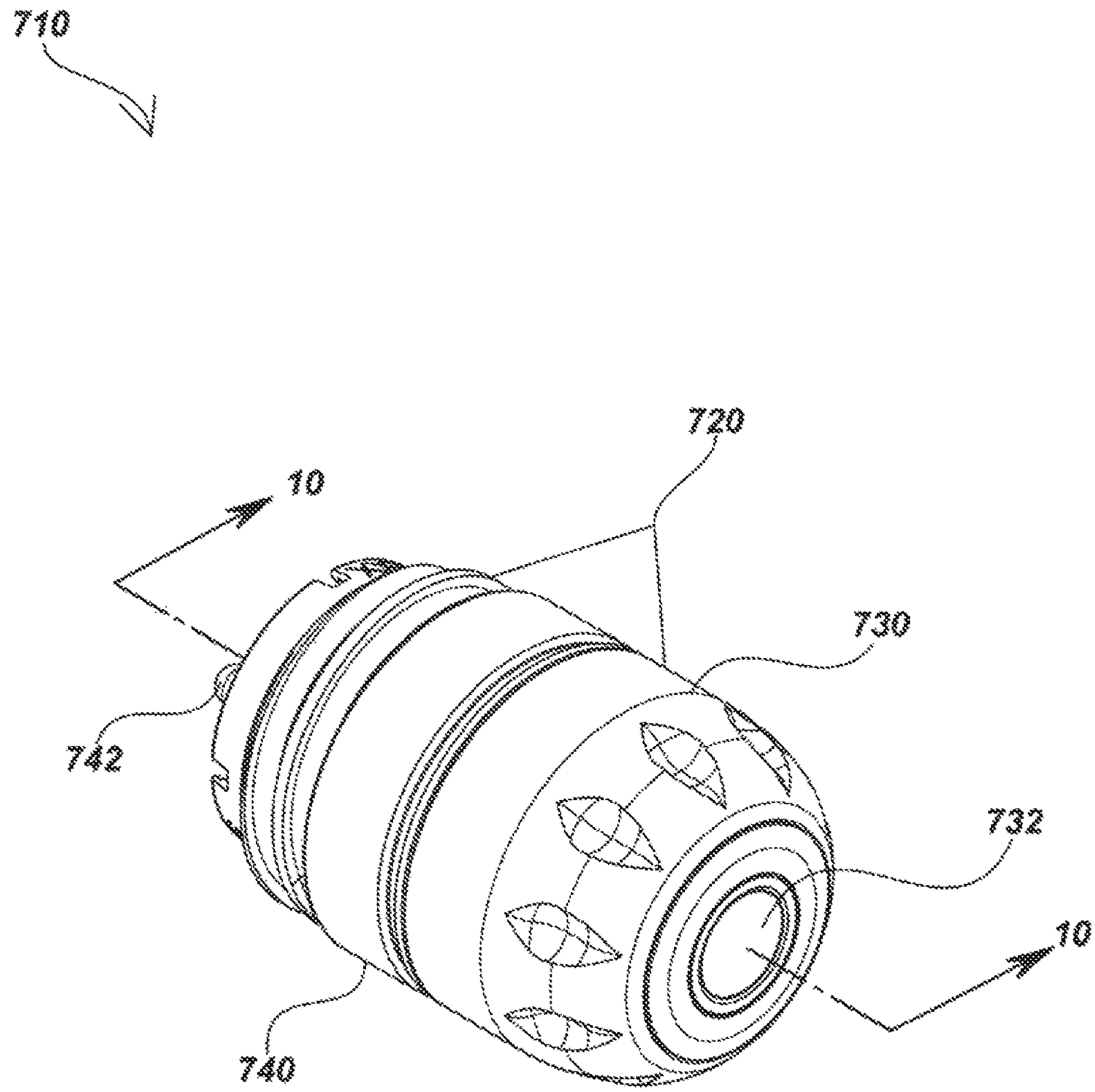

FIG. 7A

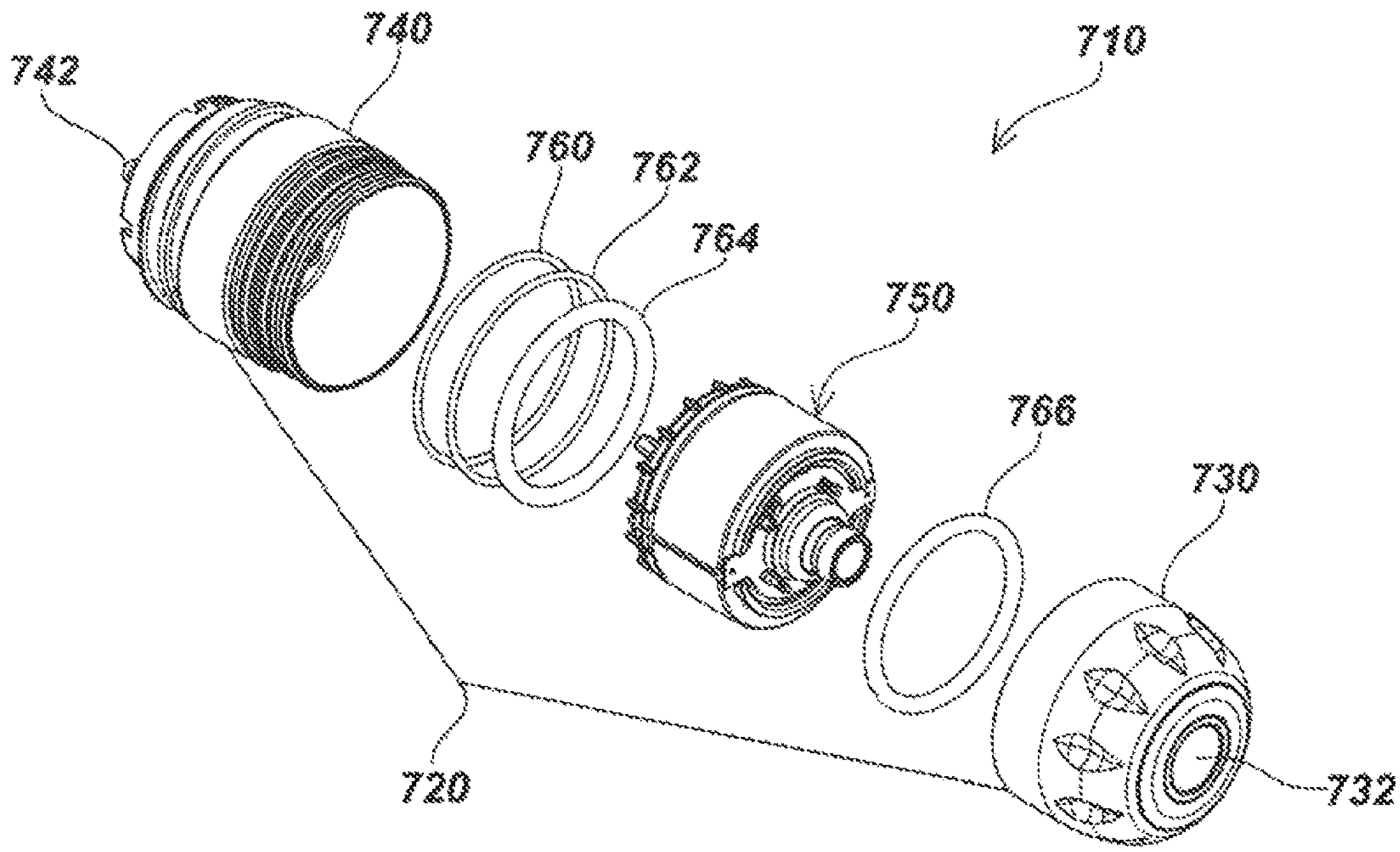
742
740
710
760
762
764
750
766
730
720
732

FIG. 7B

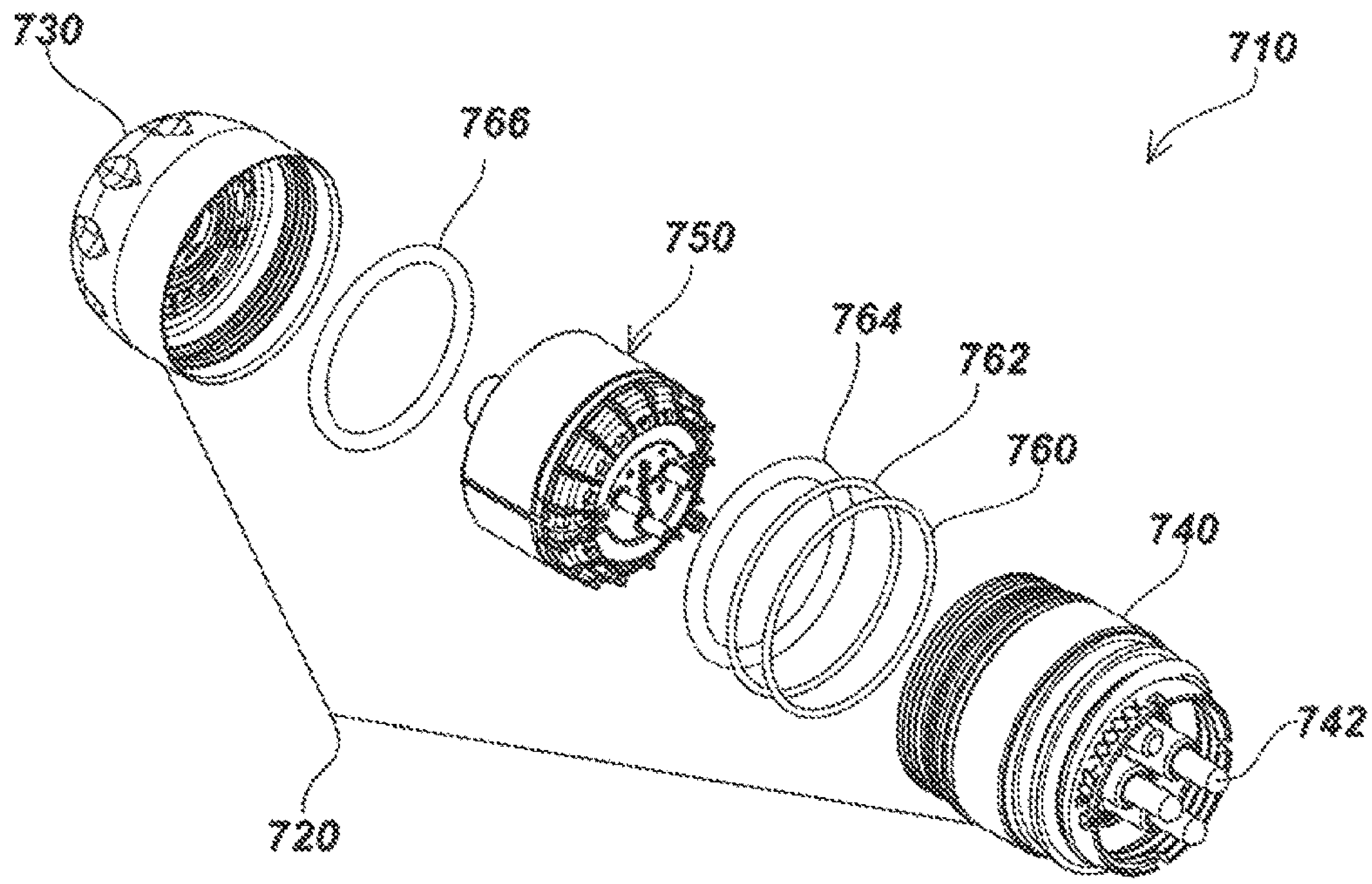
730
710
766
750
764
762
760
740
742
720

FIG. 7C

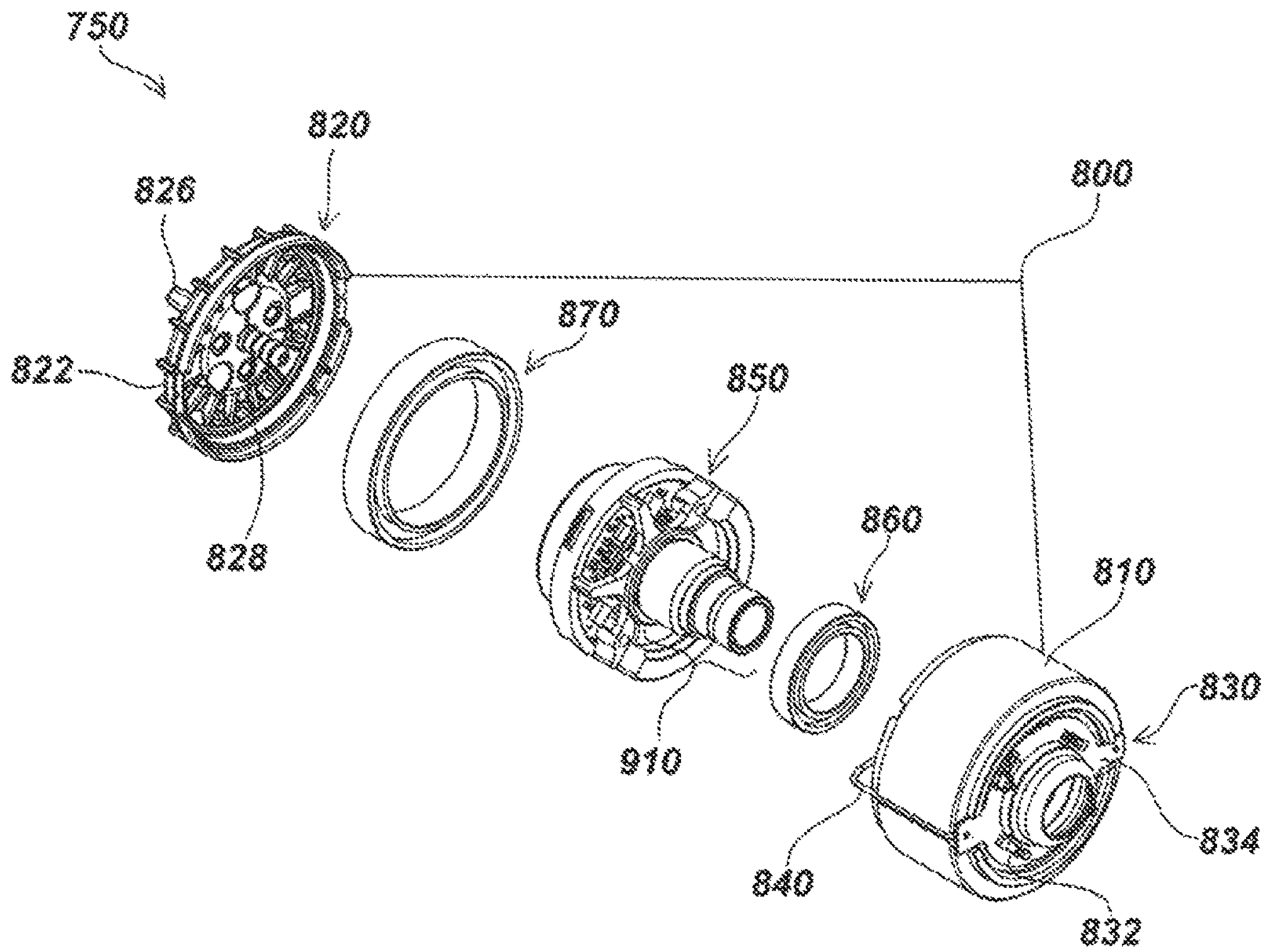
750
820
826
800
870
822
850
860
828
810
830
910
834
840
832

FIG. 8A

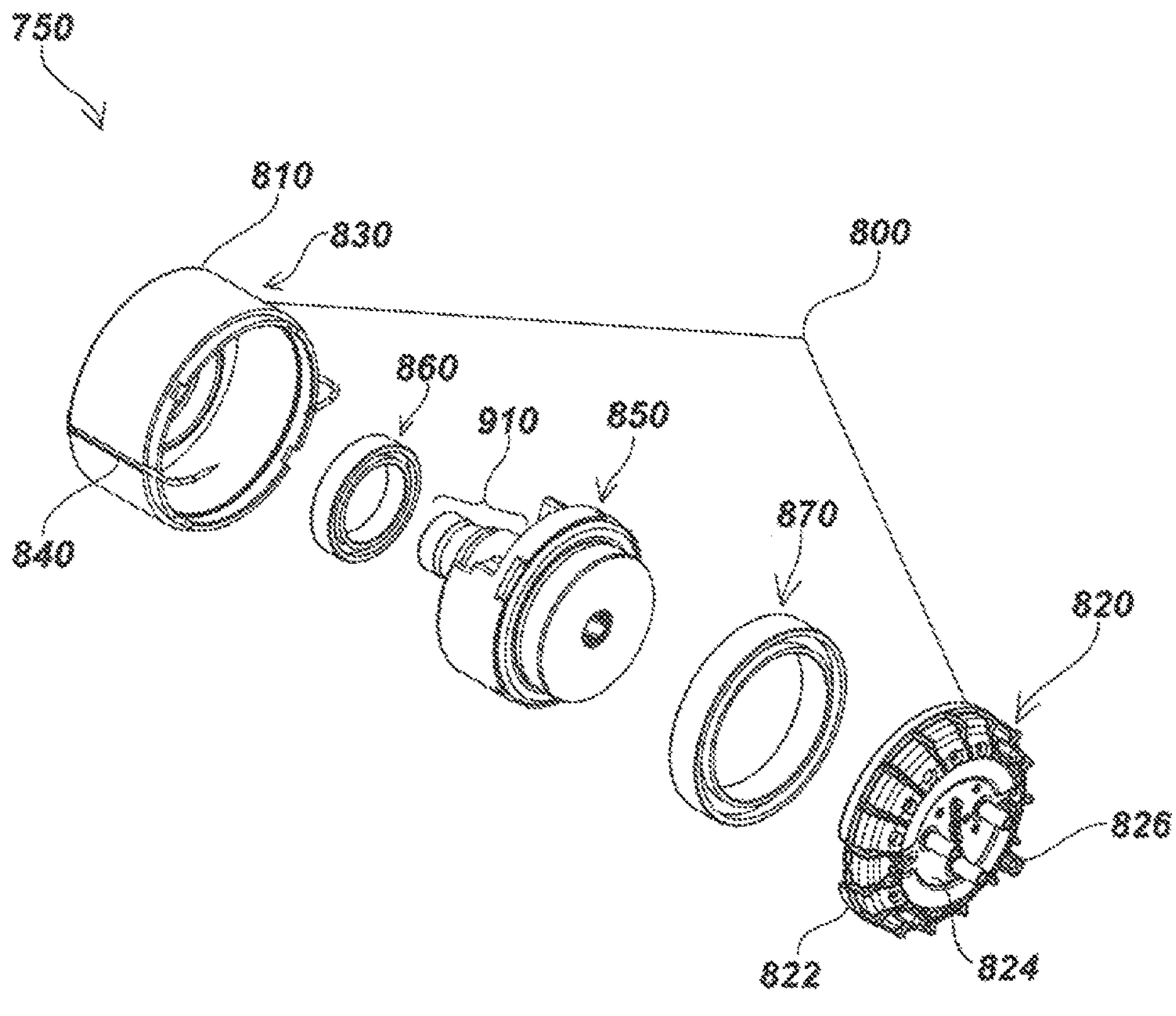
750
810
830
800
860
910
850
840
870
820
826
822
824

FIG. 8B

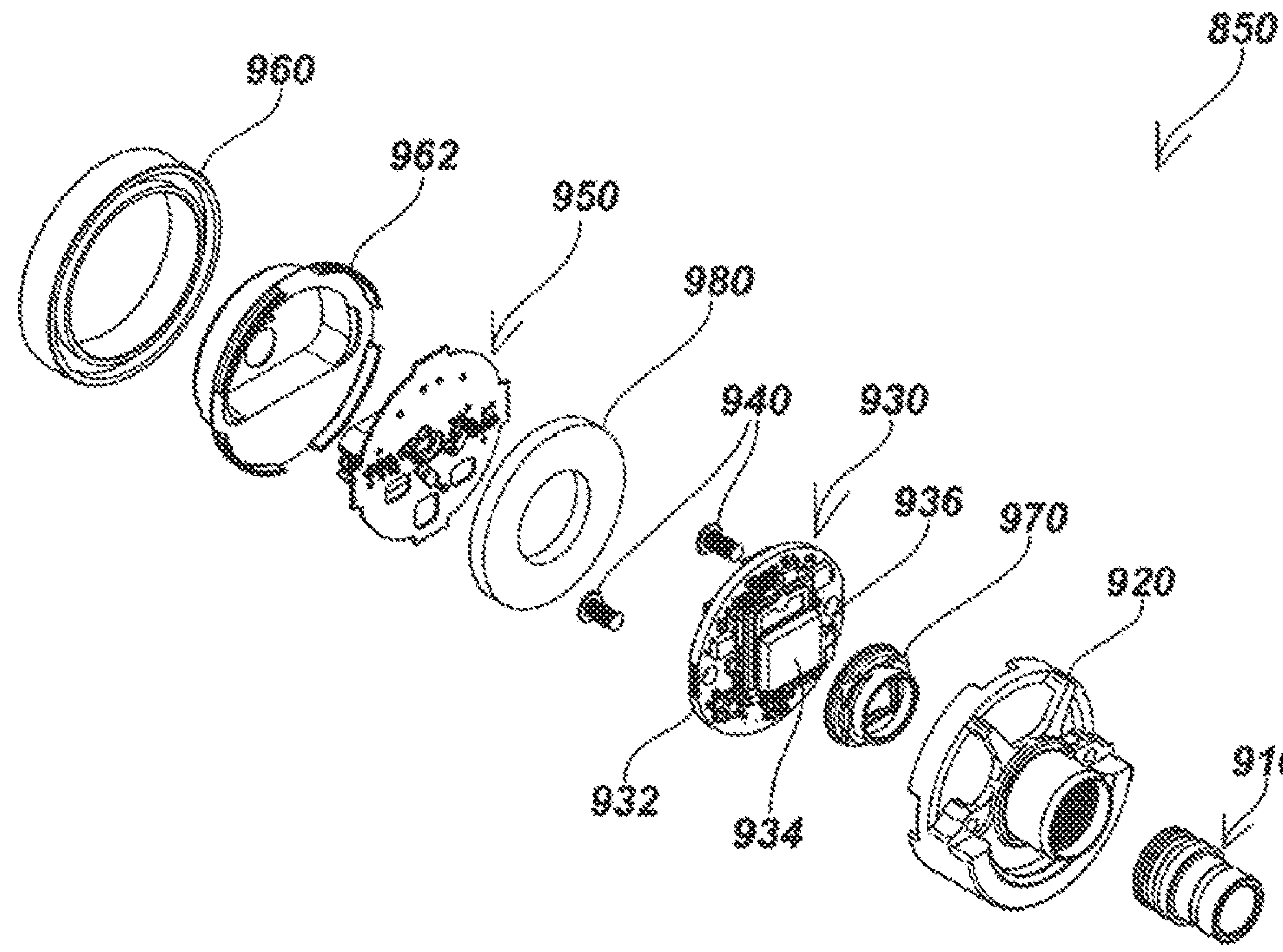
850
960
962
950
980
940
930
936
970
920
910
932
934

FIG. 9A

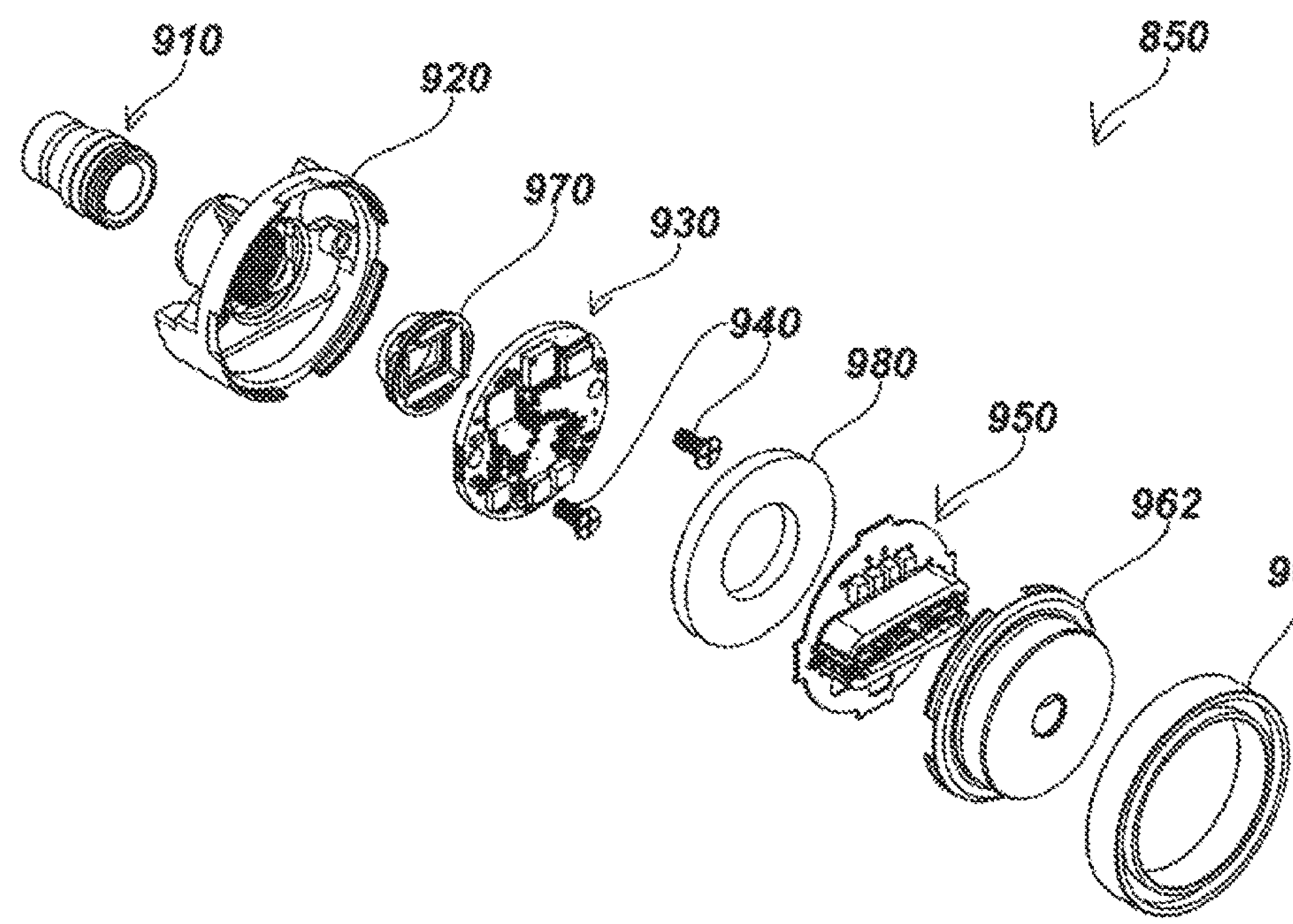
910
920
850
970
930
940
980
950
962
960

FIG. 9B

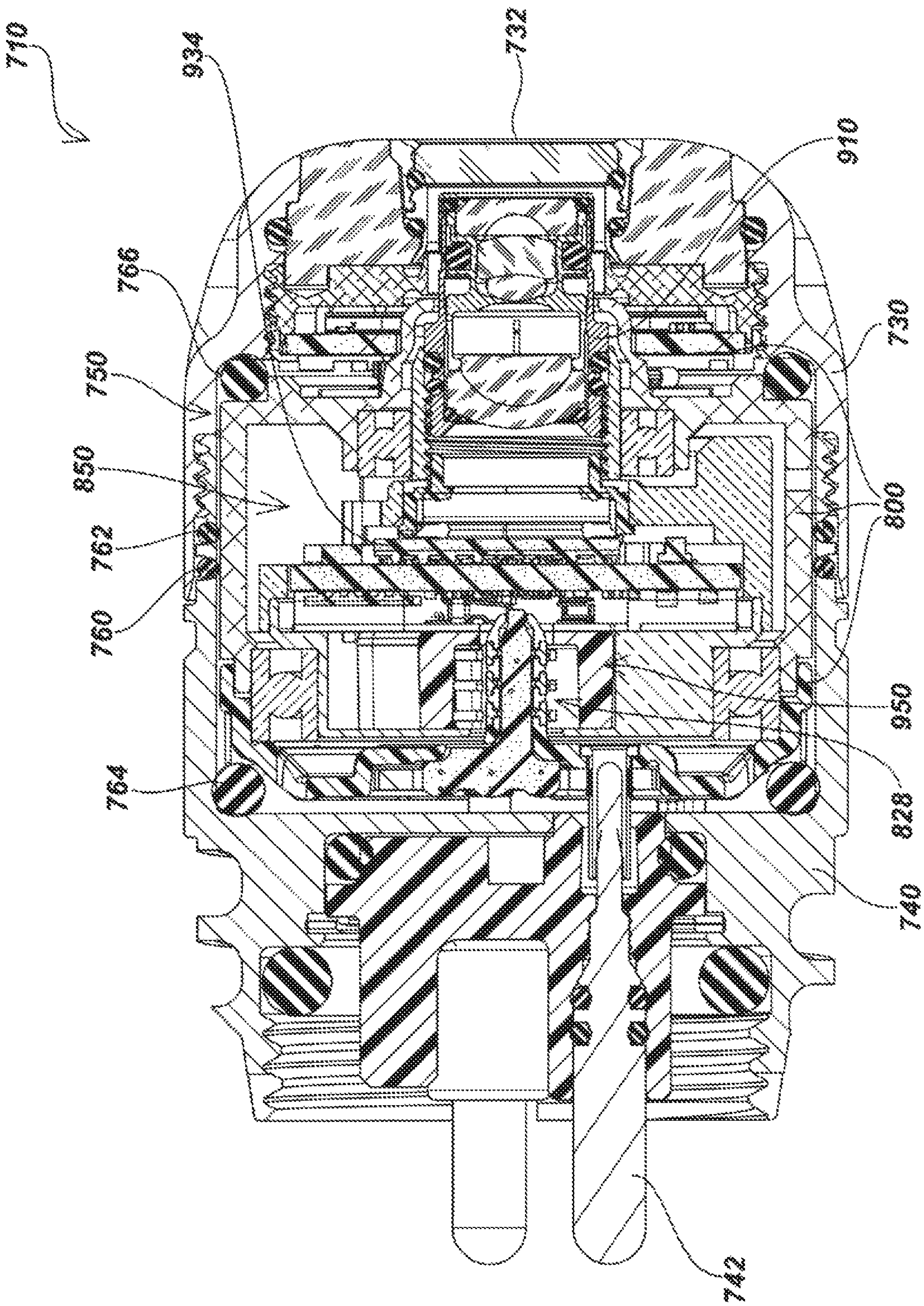

FIG. 10

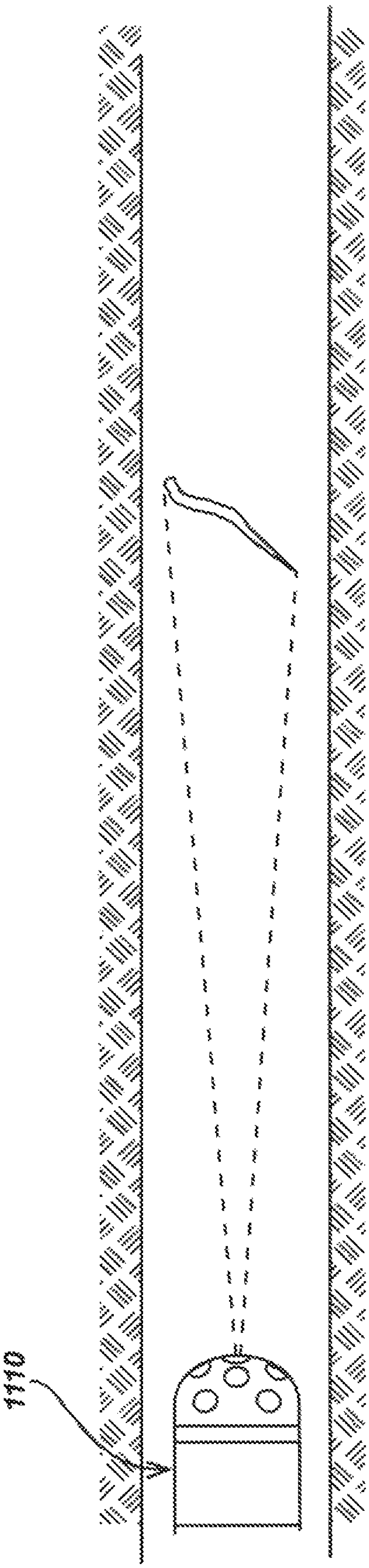

FIG. 11

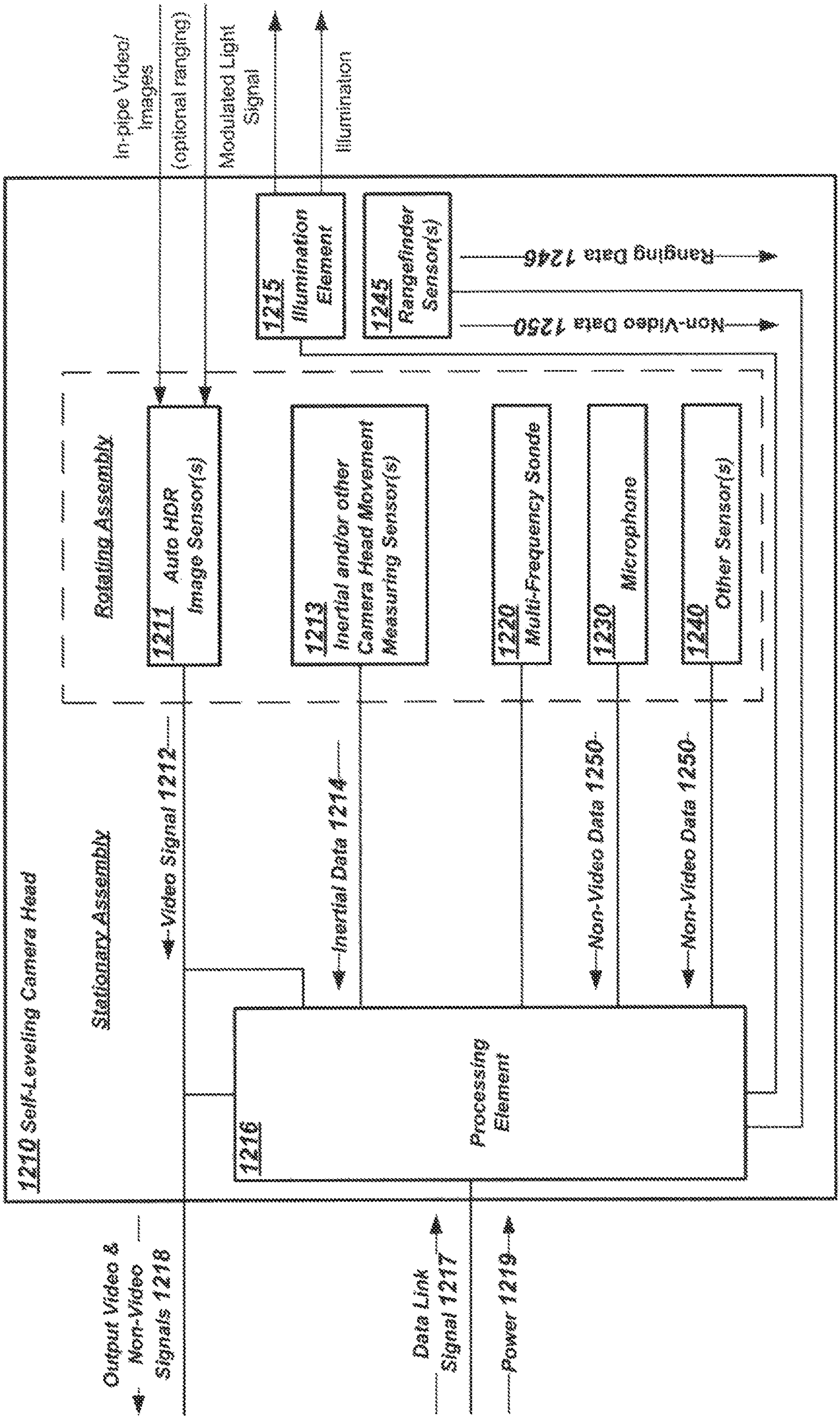
In-pipe Video/ Images
(optional ranging)
Modulated Light Signal
Illumination
1210 Self-Leveling Camera Head
1215 Illumination Element
1245 Rangefinder Sensor(s)
Ranging Data 1246
Non-Video Data 1250
Rotating Assembly
1211 Auto HDR Image Sensor(s)
1213 Inertial and/or other Camera Head Movement Measuring Sensor(s)
1220 Multi-Frequency Sonde
1230 Microphone
1240 Other Sensor(s)
Stationary Assembly
Video Signal 1212
Inertial Data 1214
Non-Video Data 1250
Non-Video Data 1250
1216 Processing Element
Output Video & Non-Video Signals 1218
Data Link Signal 1217
Power 1219

FIG. 12

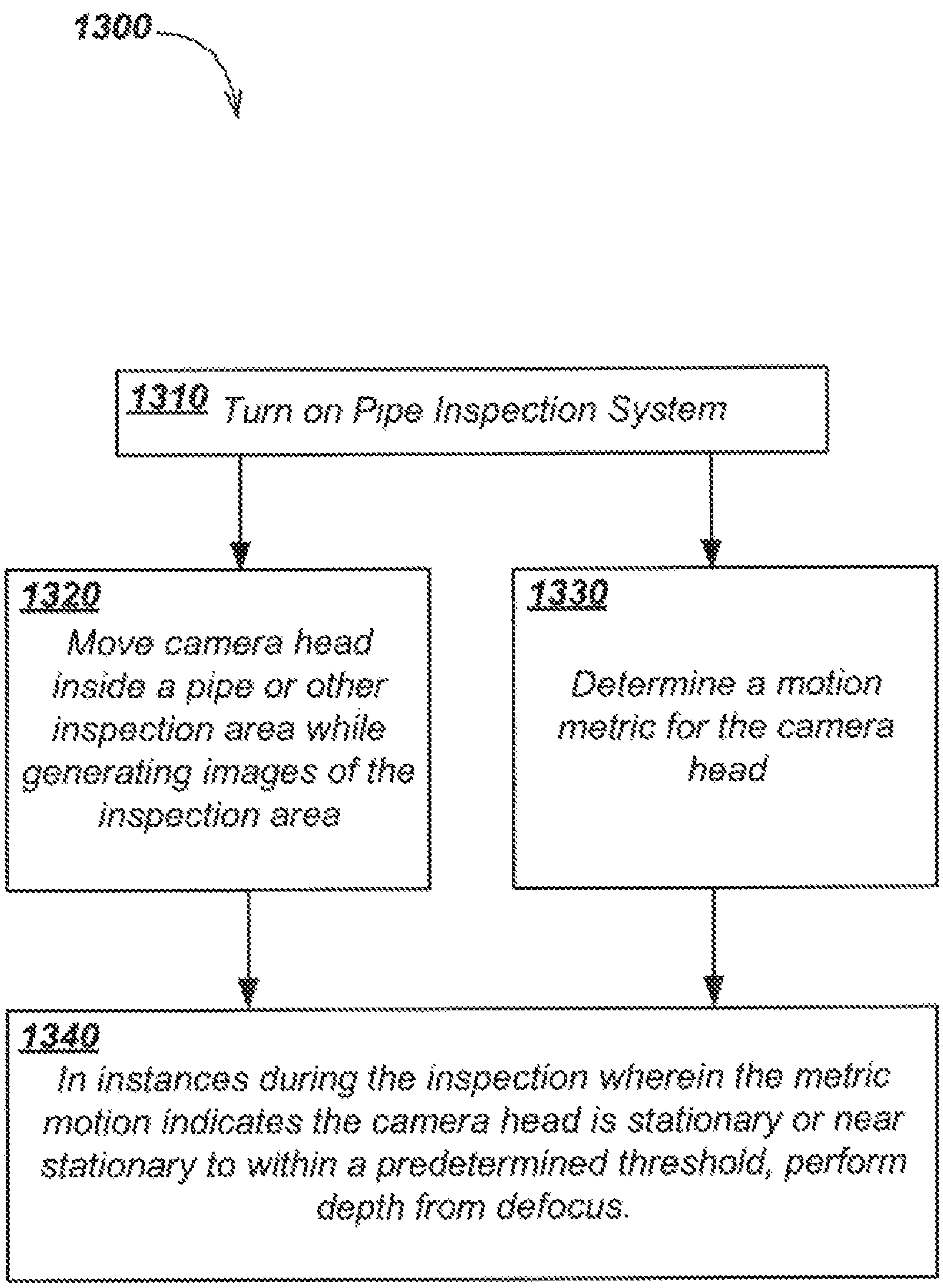
1300
1310 Turn on Pipe Inspection System
1320 Move camera head inside a pipe or other inspection area while generating images of the inspection area
1330 Determine a motion metric for the camera head
1340 In instances during the inspection wherein the metric motion indicates the camera head is stationary or near stationary to within a predetermined threshold, perform depth from defocus.

FIG. 13

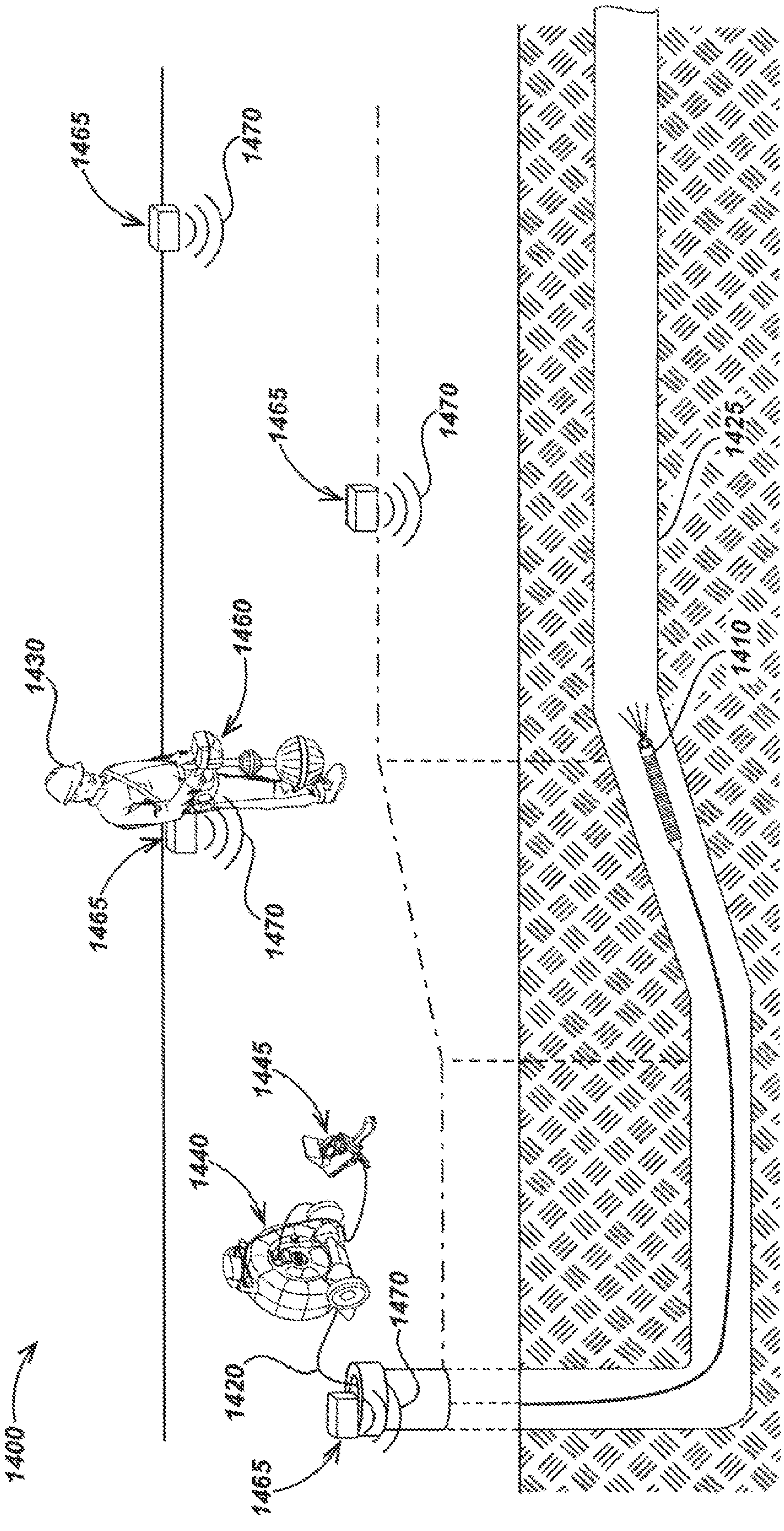

FIG. 14

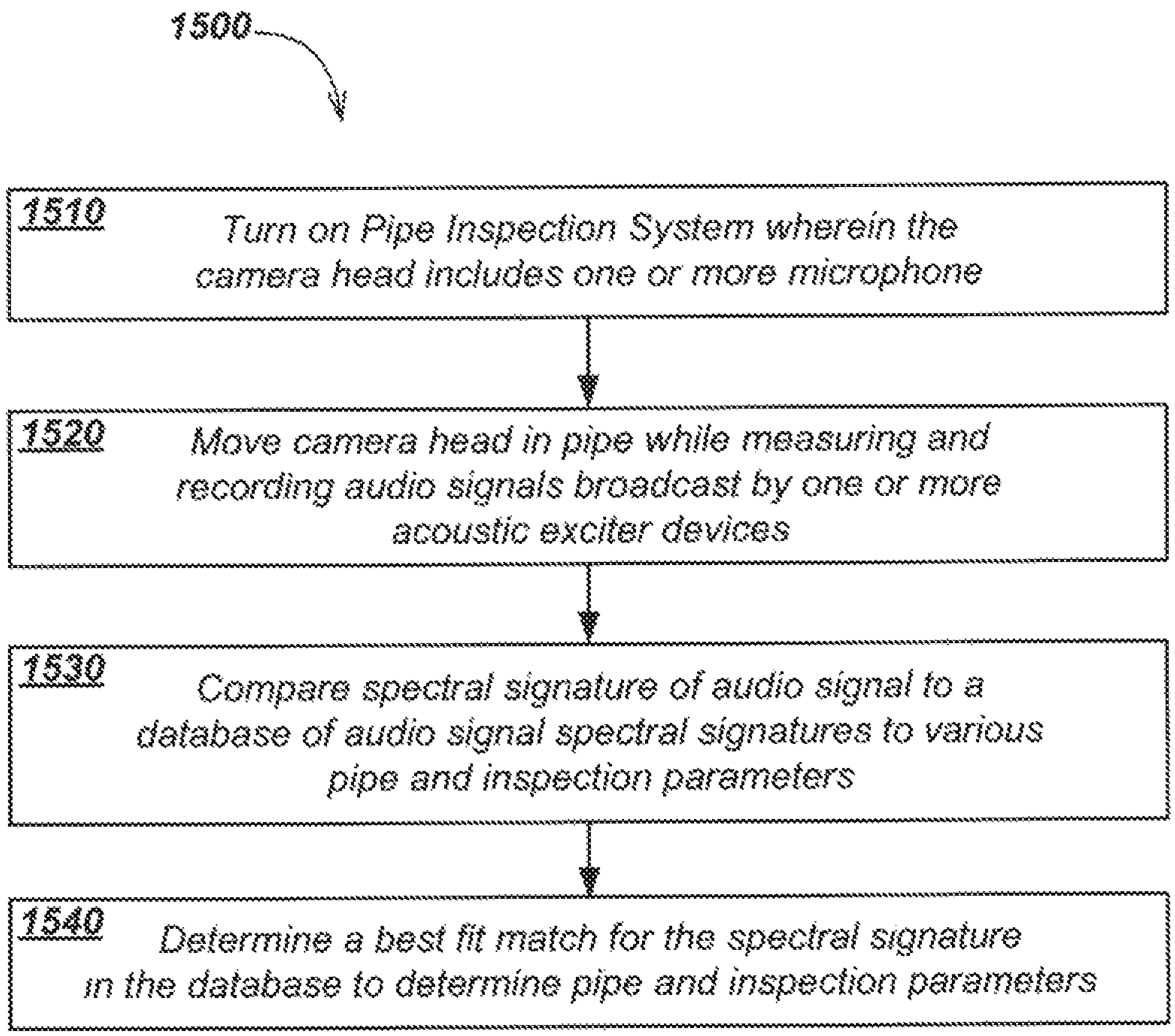
1500
1510
Turn on Pipe Inspection System wherein the camera head includes one or more microphone
1520
Move camera head in pipe while measuring and recording audio signals broadcast by one or more acoustic exciter devices
1530
Compare spectral signature of audio signal to a database of audio signal spectral signatures to various pipe and inspection parameters
1540
Determine a best fit match for the spectral signature in the database to determine pipe and inspection parameters

FIG. 15

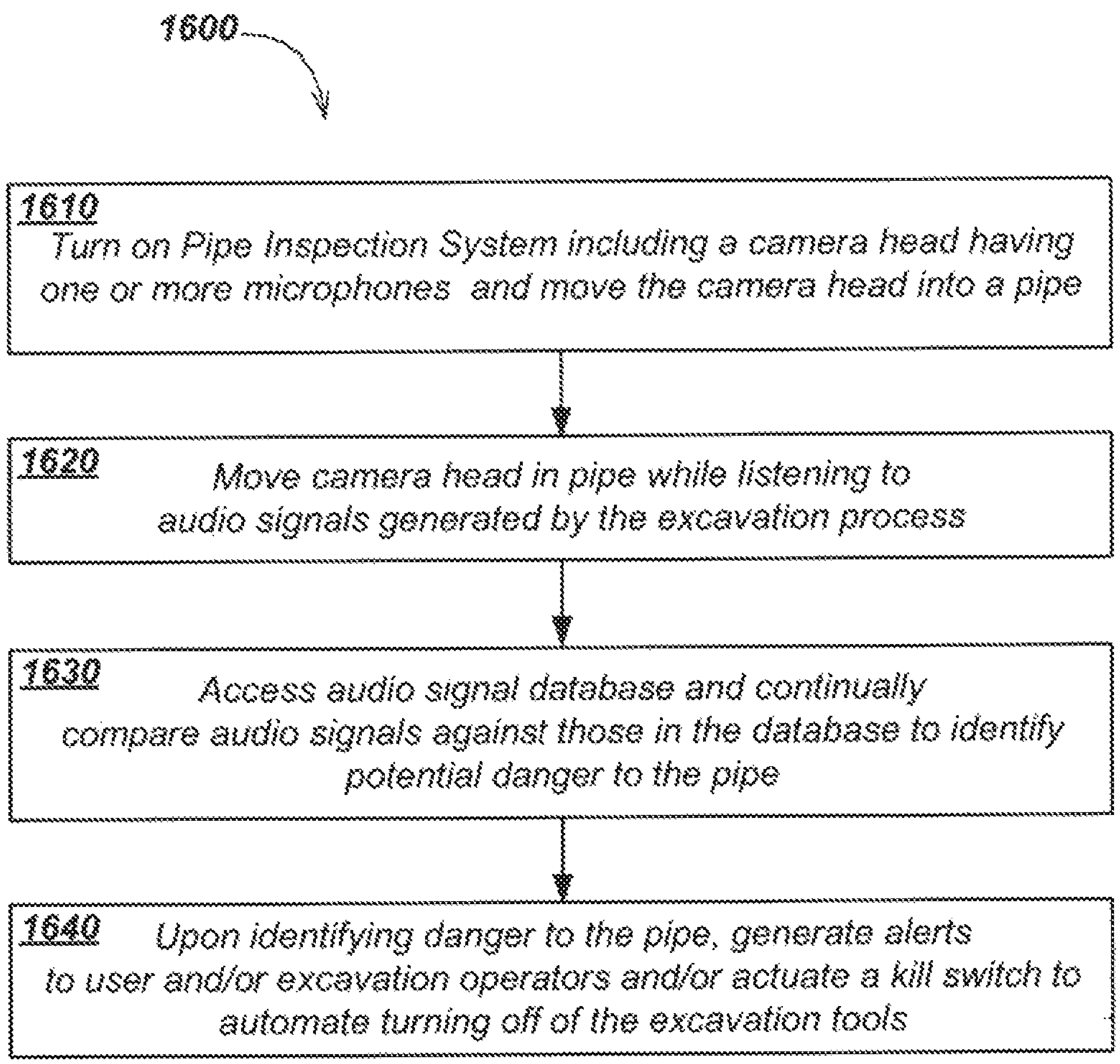
1600
1610
Turn on Pipe Inspection System including a camera head having one or more microphones and move the camera head into a pipe
1620
Move camera head in pipe while listening to audio signals generated by the excavation process
1630
Access audio signal database and continually compare audio signals against those in the database to identify potential danger to the pipe
1640
Upon identifying danger to the pipe, generate alerts to user and/or excavation operators and/or actuate a kill switch to automate turning off of the excavation tools

FIG. 16

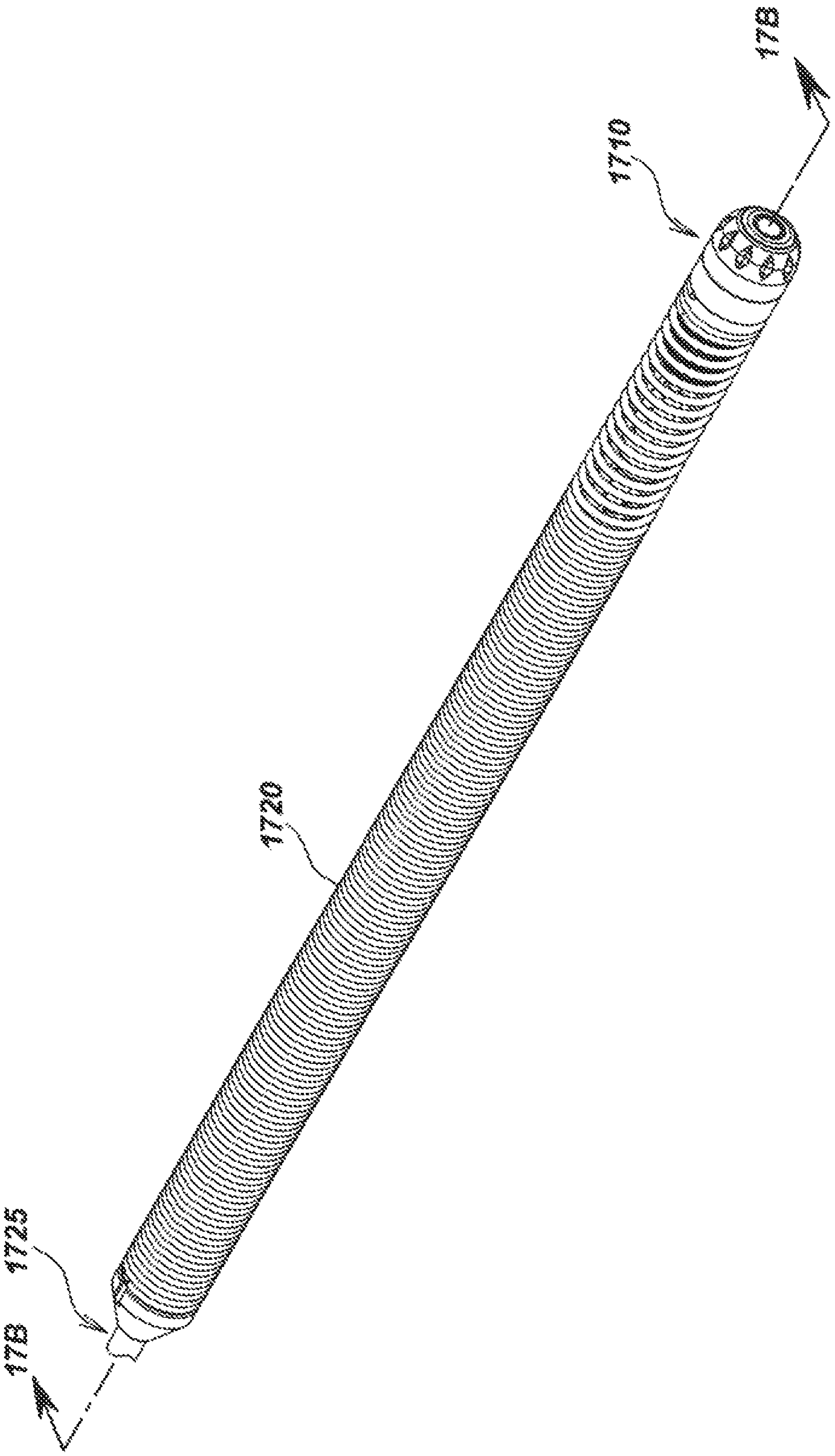

FIG. 17A

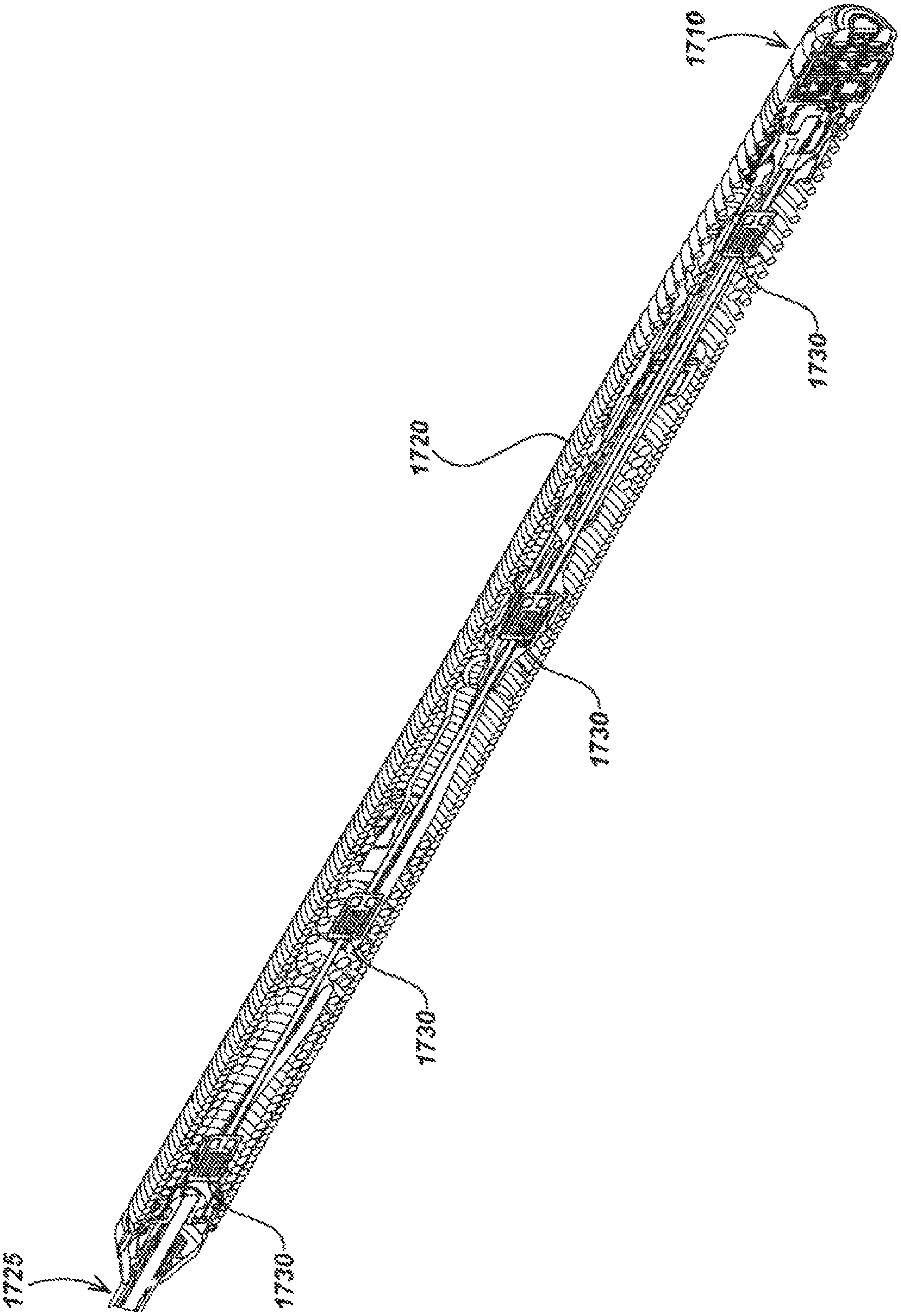

FIG. 17B

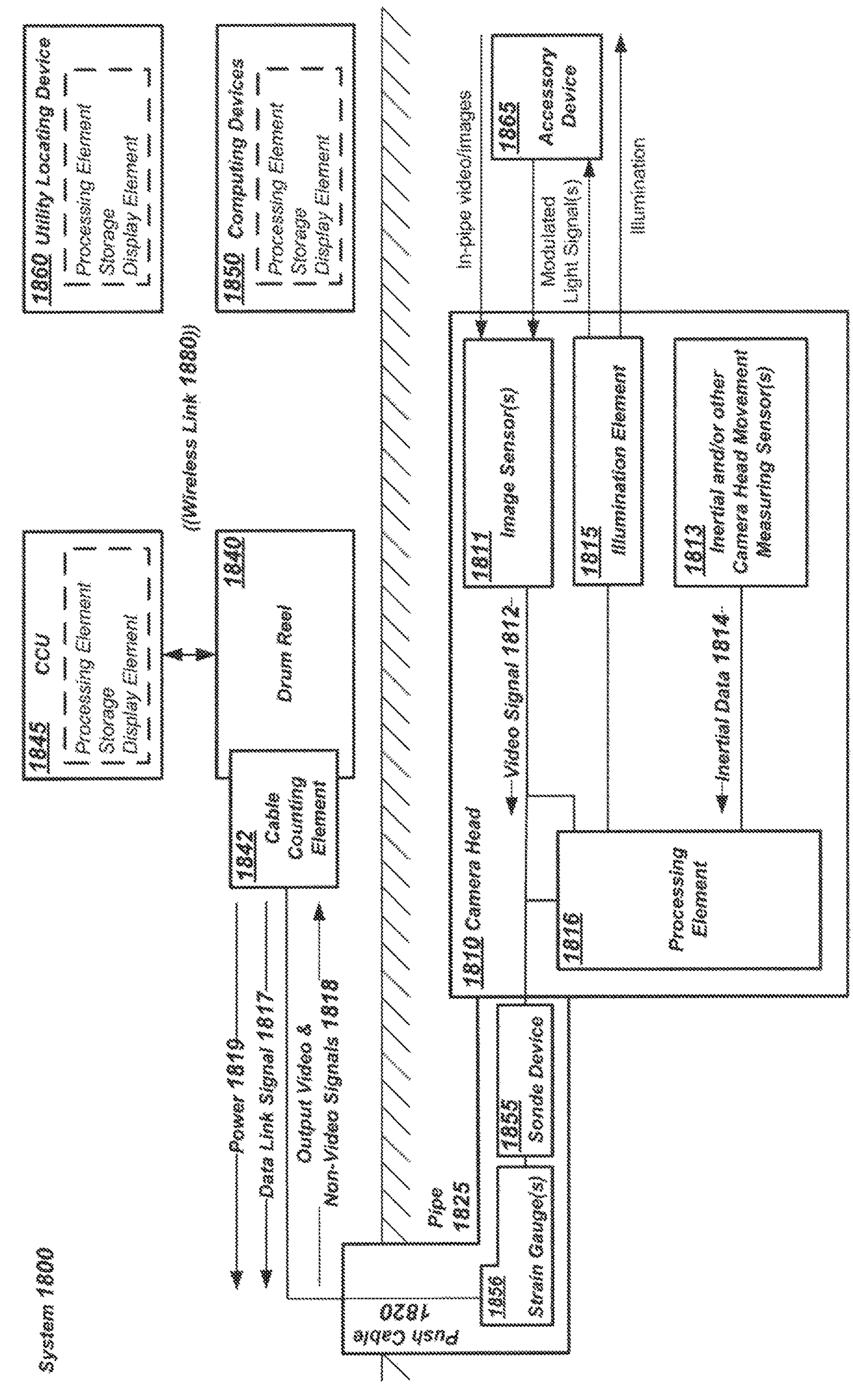
System 1800
1860 Utility Locating Device
Processing Element
Storage
Display Element
1850 Computing Devices
Processing Element
Storage
Display Element
1845 CCU
Processing Element
Storage
Display Element
((Wireless Link 1880))
1840
Drum Reel
1842 Cable Counting Element
Power 1819
Data Link Signal 1817
Output Video & Non-Video Signals 1818
Pipe 1825
Push Cable 1820
1856 Strain Gauge(s)
1855 Sonde Device
1810 Camera Head
1811 Image Sensor(s)
Video Signal 1812
1815 Illumination Element
1813 Inertial and/or other Camera Head Movement Measuring Sensor(s)
Inertial Data 1814
1816 Processing Element
In-pipe video/images
Modulated Light Signal(s)
Illumination
1865 Accessory Device

FIG. 18

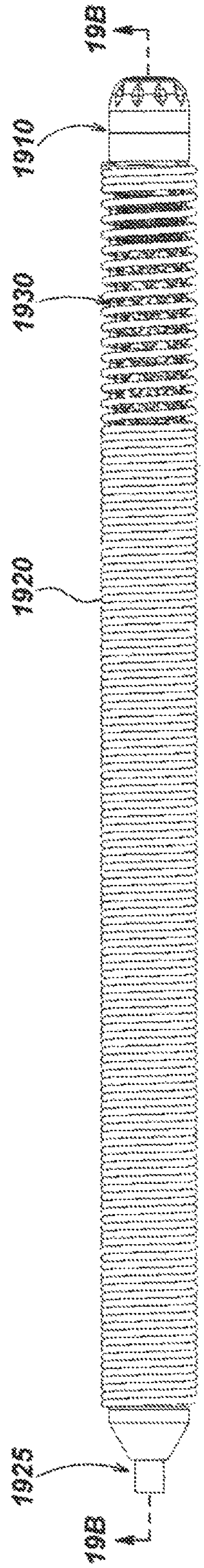

FIG. 19A

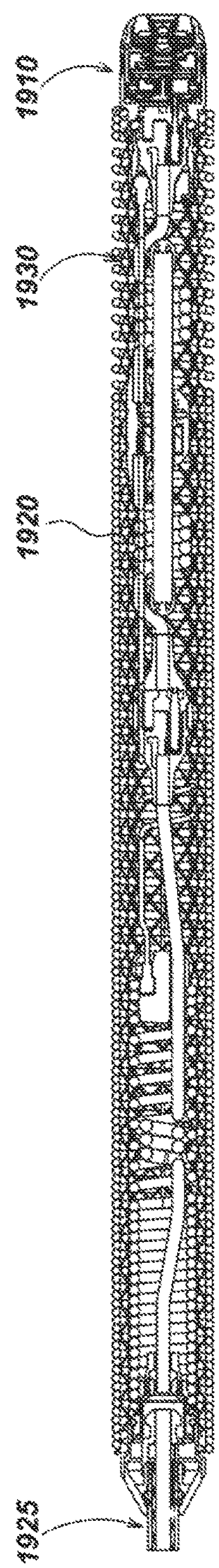

FIG. 19B

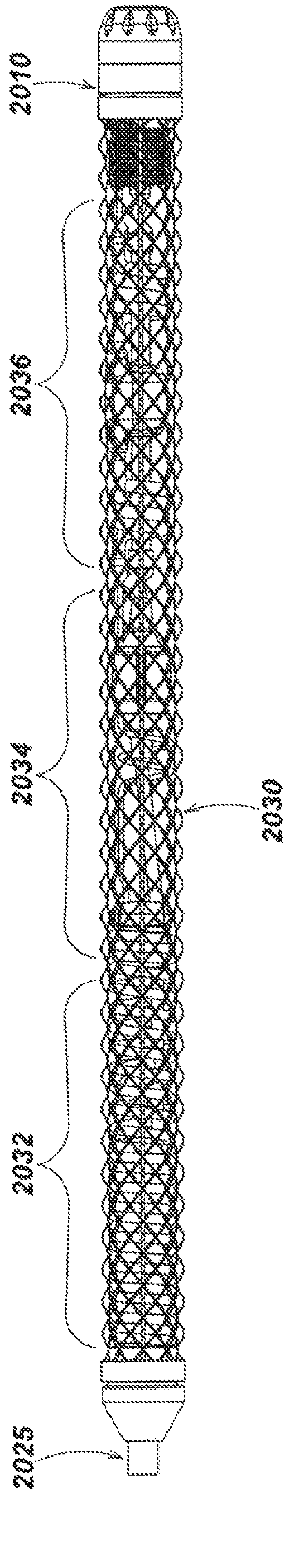

FIG. 20

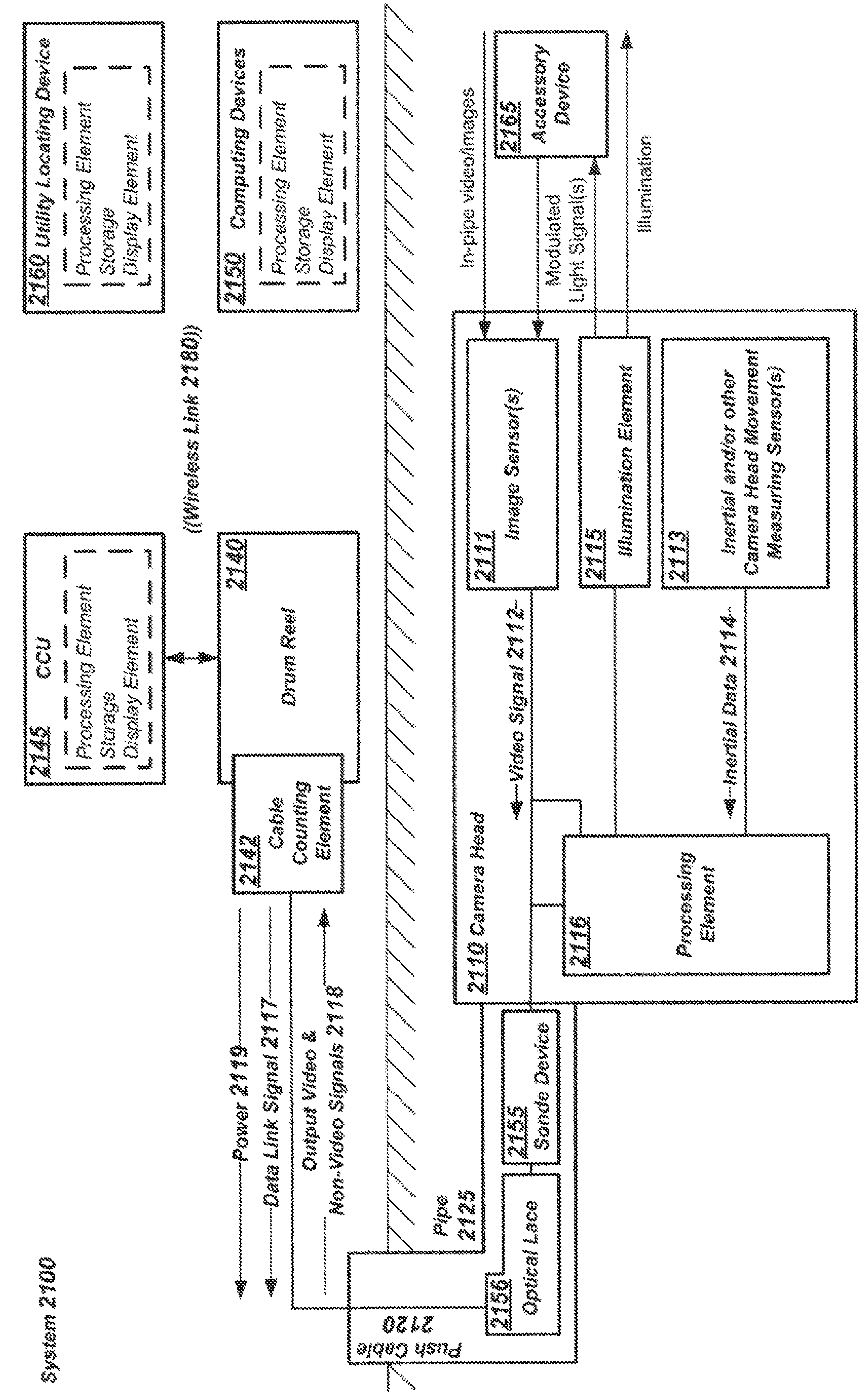
System 2100
2160 Utility Locating Device
Processing Element
Storage
Display Element
2150 Computing Devices
Processing Element
Storage
Display Element
2145 CCU
Processing Element
Storage
Display Element
((Wireless Link 2180))
2140 Drum Reel
2142 Cable Counting Element
Power 2119
Data Link Signal 2117
Output Video & Non-Video Signals 2118
Pipe 2125
Push Cable 2120
2156 Optical Lace
2155 Sonde Device
2110 Camera Head
2111 Image Sensor(s)
2115 Illumination Element
2113 Inertial and/or other Camera Head Movement Measuring Sensor(s)
2116 Processing Element
Video Signal 2112
Inertial Data 2114
In-pipe video/images
Modulated Light Signal(s)
Illumination
2165 Accessory Device

FIG. 21

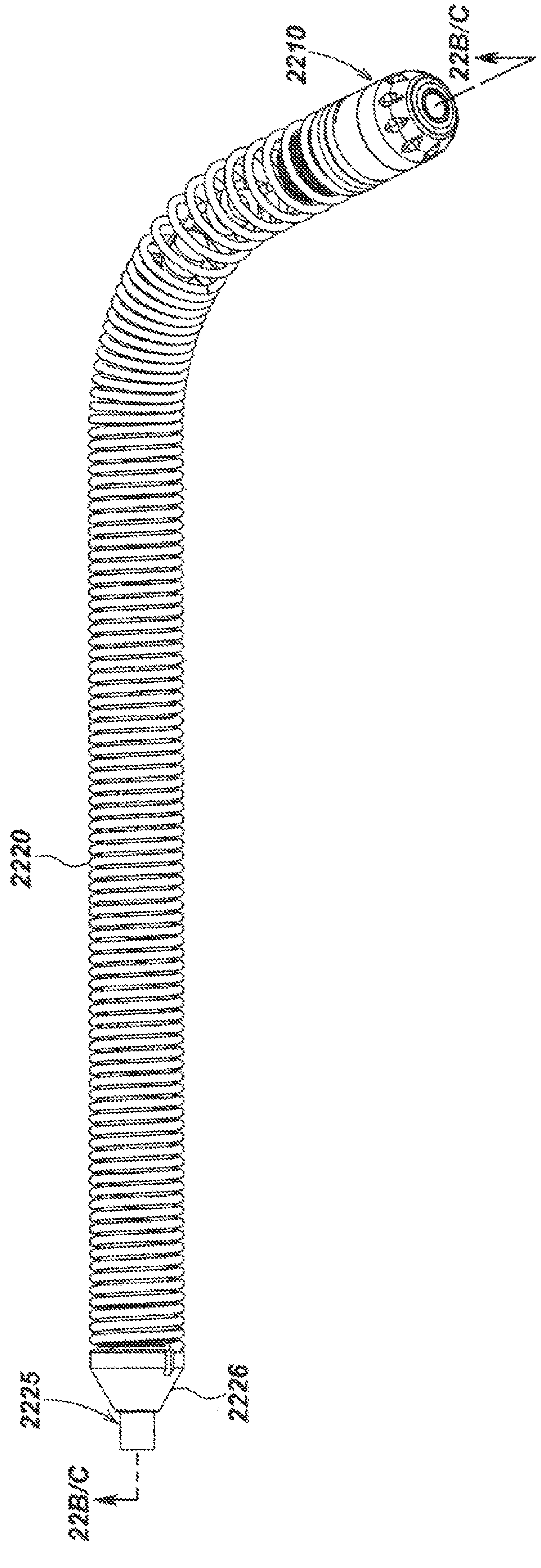

FIG. 22A

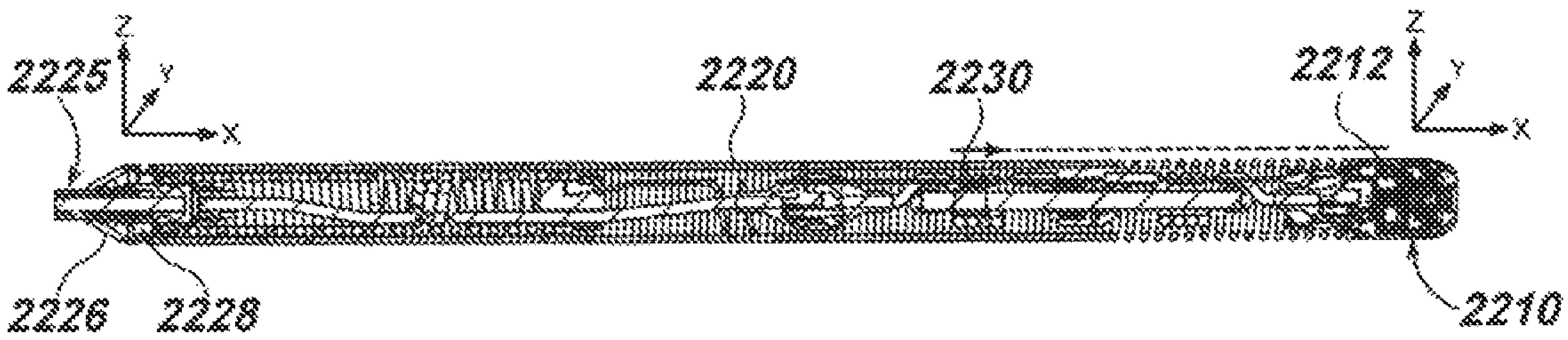

FIG. 22B

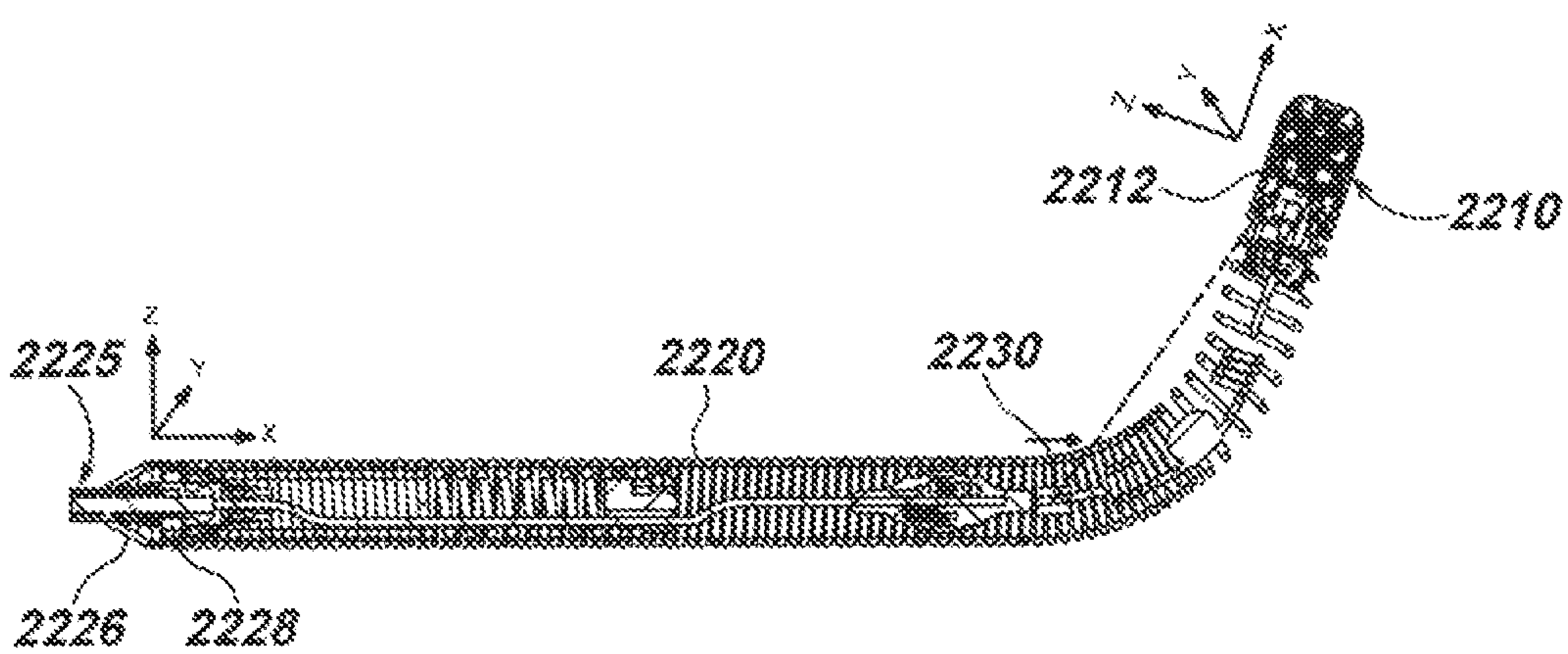

FIG. 22C

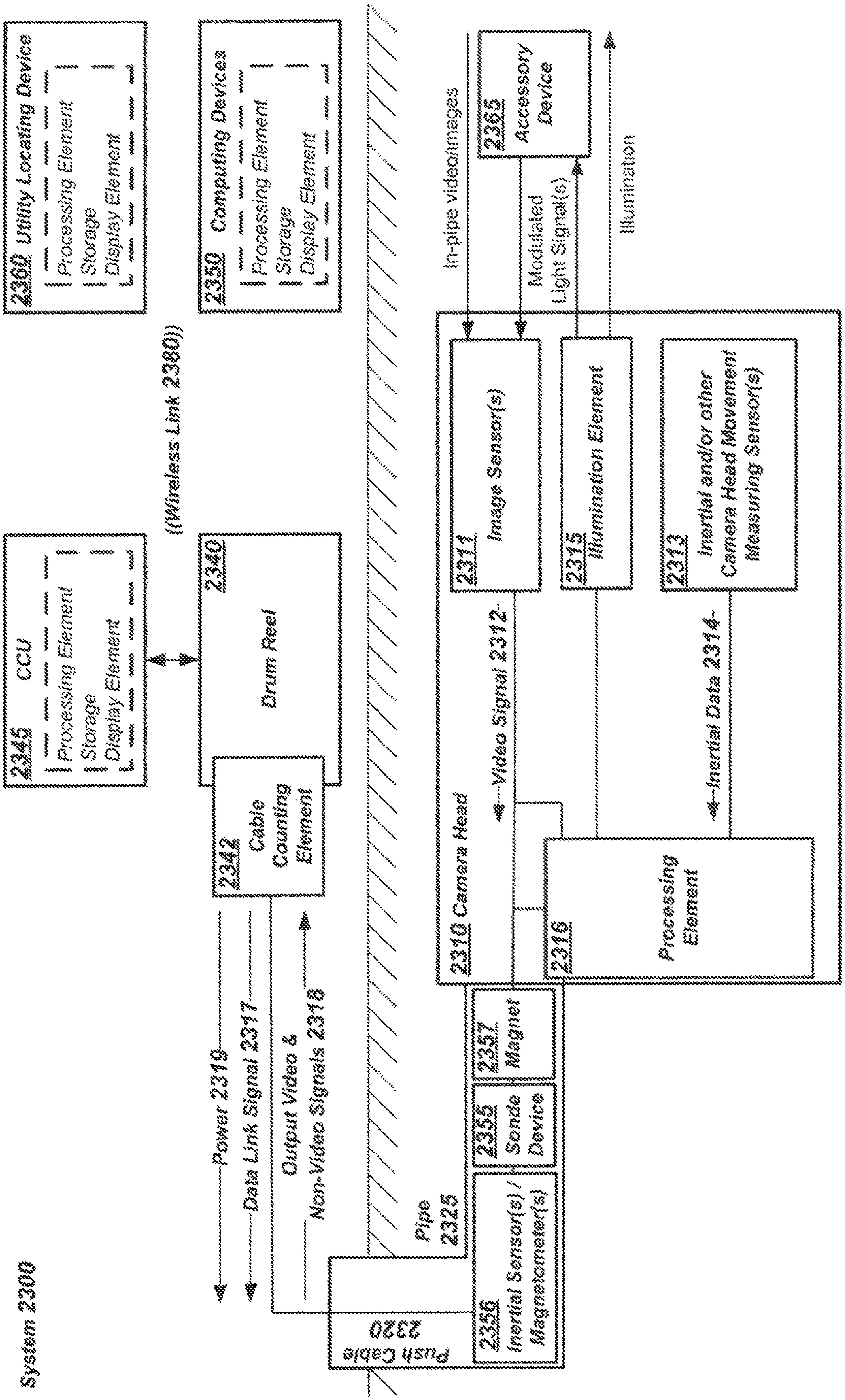
System 2300
2360 Utility Locating Device
Processing Element
Storage
Display Element
2350 Computing Devices
Processing Element
Storage
Display Element
2345 CCU
Processing Element
Storage
Display Element
((Wireless Link 2380))
2340 Drum Reel
2342 Cable Counting Element
Power 2319
Data Link Signal 2317
Output Video & Non-Video Signals 2318
Push Cable 2320
Pipe 2325
2356 Inertial Sensor(s) / Magnetometer(s)
2355 Sonde Device
2357 Magnet
2310 Camera Head
Video Signal 2312
Inertial Data 2314
2316 Processing Element
2311 Image Sensor(s)
2315 Illumination Element
2313 Inertial and/or other Camera Head Movement Measuring Sensor(s)
In-pipe video/images
Modulated Light Signal(s)
Illumination
2365 Accessory Device

FIG. 23

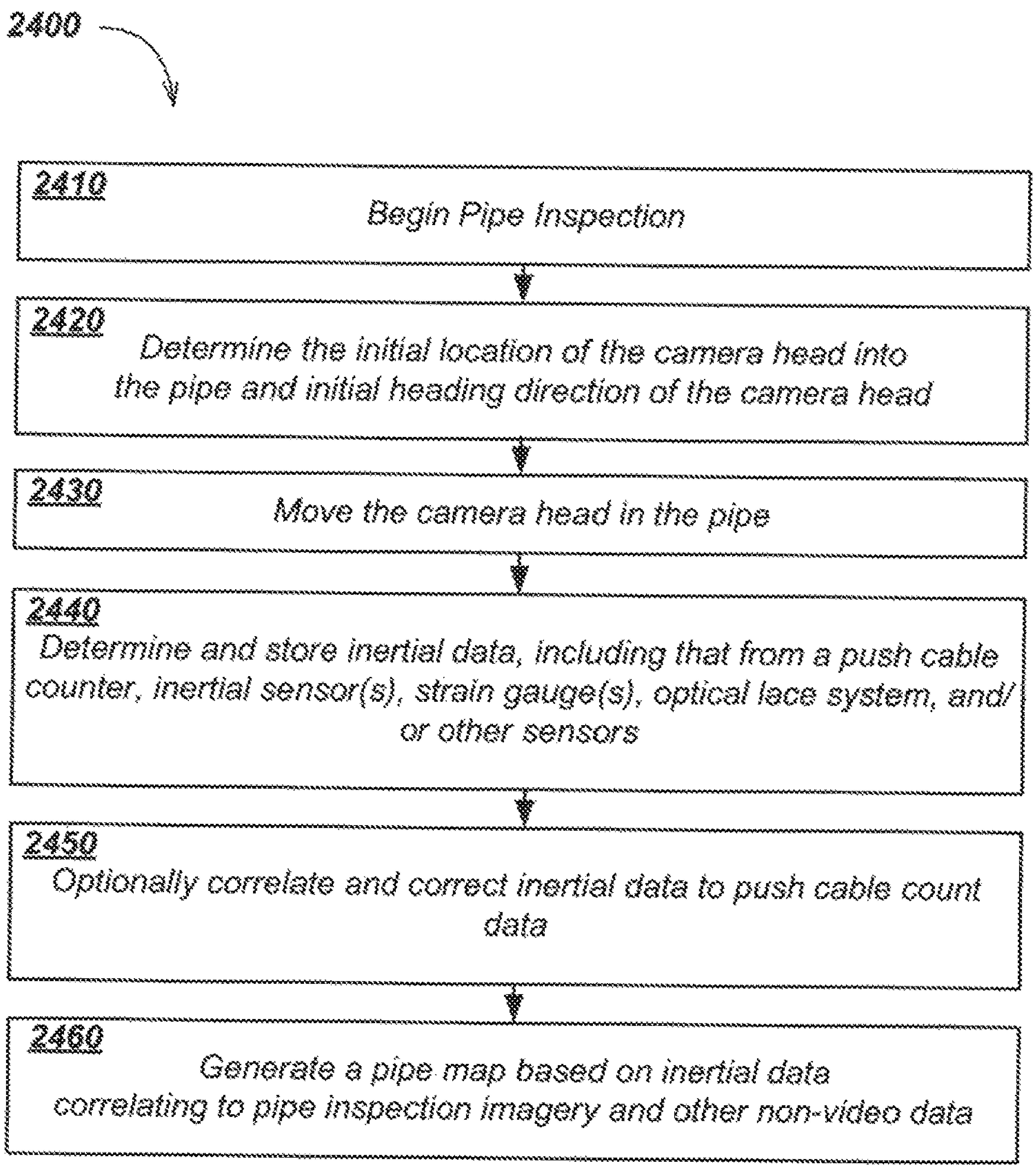
2400
2410
Begin Pipe Inspection
2420
Determine the initial location of the camera head into the pipe and initial heading direction of the camera head
2430
Move the camera head in the pipe
2440
Determine and store inertial data, including that from a push cable counter, inertial sensor(s), strain gauge(s), optical lace system, and/or other sensors
2450
Optionally correlate and correct inertial data to push cable count data
2460
Generate a pipe map based on inertial data correlating to pipe inspection imagery and other non-video data

FIG. 24

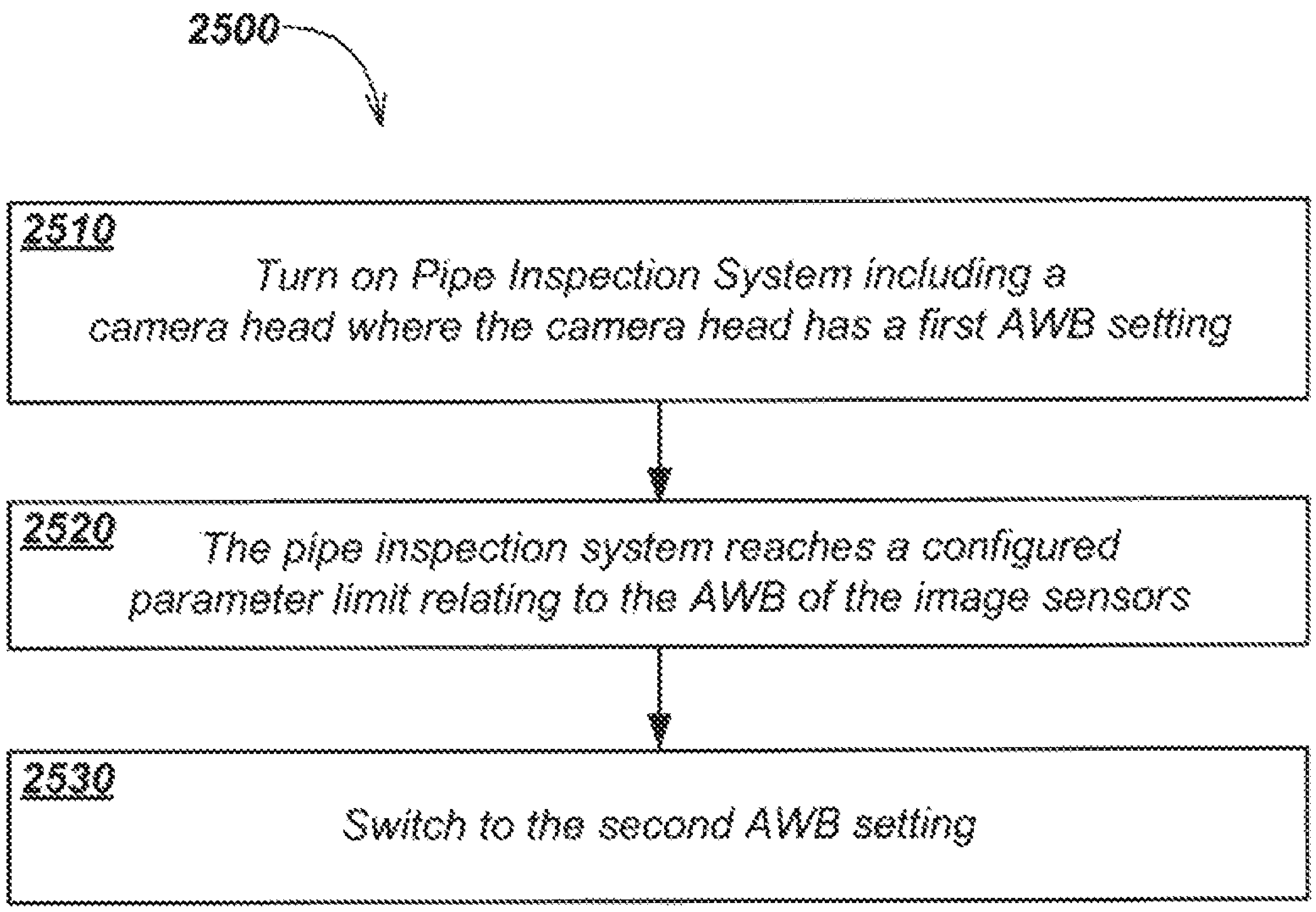
2500
2510
Turn on Pipe Inspection System including a camera head where the camera head has a first AWB setting
2520
The pipe inspection system reaches a configured parameter limit relating to the AWB of the image sensors
2530
Switch to the second AWB setting

FIG. 25

PIPE INSPECTION AND/OR MAPPING CAMERA HEADS, SYSTEMS, AND METHODS

FIELD

This disclosure relates generally to pipe inspection and/or mapping. More specifically, but not exclusively, this disclosure relates to pipe inspection and/or mapping camera heads, including high dynamic range camera heads, for inspecting and/or mapping an interior of pipes, cavities, or other conduits.

BACKGROUND

There are many situations where it is desirable to internally inspect pipes or other difficult to access cavities or voids that are already in place, whether underground, in a building, or underwater. For example, various utility pipes (e.g., sewer, water, gas, electrical conduits, fiber optic conduits, or the like) frequently must be internally inspected to diagnose any existing problems and to determine if there are any breaks causing leakage or obstructions impairing the free flow of waste. Likewise, such pipes may often require excavation for repair, improvement, or other servicing. Precise mapping of such pipes may be instrumental in avoiding damage to infrastructure and thereby avoiding hazardous situations to crews performing the excavation.

Traditional systems and method for inspecting the pipes include a camera head disposed on a push cable that may be forced down a pipe to display the interior of the pipe on a camera control unit (CCU) or other video display. Such pipe inspection camera heads and associated systems, devices, and methods visually inspect the interior of the pipes and to identify defects caused by, for example, ingress of roots; pipe cracks or breaks; corrosion; leakage; and/or other defects or blockages inside the pipe. Camera heads and associated systems and devices known in the art configured to produce in pipe imagery are limited in exposure range thus making elements existing in the pipe often difficult to discern by one or more human operators. Such limitations in pipe imagery often result in situations where problems existing inside the pipe may be missed or otherwise misdiagnosed by the system operator(s). Further, traditional camera heads and associated devices and systems are generally lacking in functionality to provide an array of other inspection and camera head data which may be useful in the inspection and mapping of pipes.

Accordingly, there is a need in the art to address the above-described as well as other problems.

SUMMARY

This disclosure relates generally to camera heads and pipe inspection and/or mapping systems and methods used to inspect and/or map the interior of pipes and other conduits, cavities, or voids. More specifically, but not exclusively, this disclosure relates to pipe inspection and mapping camera heads, including high dynamic range camera heads, as used in pipe inspection and mapping systems and methods for enhanced inertial data and improved pipe mapping.

According to one aspect, a camera head may be coupled to a push-cable and may include one or more image sensors to capture images and/or videos from interior of the pipe or cavity. One or more multi-axis sensors may be disposed in the camera head to sense data corresponding to movement of the camera head within the pipe or cavity. The images and/or

videos captured by the image sensors may be used in conjunction with the data sensed by the multi-axis sensors to generate information pertaining to the pipe or cavity may be generated.

According to another aspect, a system for inspecting and/or mapping a pipe or avity may include a cable storage drum, a push-cable stored in turns inside the cable storage drum and having a distal end and a proximal end, a camera head coupled to the distal end of the push-cable. The camera head may include one or more image sensors to capture images and/or videos from the interior of a pipe or cavity. The camera head may be movable in a first direction when the push-cable is deployed into the pipe or cavity and a second direction when the push-cable is retracted from the pipe or cavity. The system may further include a multi-axis inertial sensor disposed in the camera head to sense three dimensional inertial data corresponding to movement of the camera head in the first direction and the second direction, and a processing element communicatively coupled to the image sensors and the inertial sensor, to receive the images and/or videos from the image sensors and the sensed inertial data from the inertial sensor. Based at least on the received images and/or videos and the inertial data sensed during movement of the camera head in the first direction and the second direction, the processing element may generate information pertaining to the pipe or cavity.

The system may further include a cable counter to generate cable count data indicative of an amount of cable dispensed or retracted to/from the cable storage drum. The processing element may receive such cable count data and correlate, based at least on the cable count data, the inertial data sensed in the first direction and the second direction. The processing element may associate the images and/or videos of the pipe or cavity with the correlated data to generate a pipe map. The pipe map may include one or more location points corresponding to location points on a ground surface.

According to another aspect, a camera head for inspecting and/or mapping a pipe or cavity may include an outer housing having a hollow interior and a camera module assembly disposed in the hollow interior. The camera module assembly may include a rotating assembly rotatable relative to the outer housing, a stationary assembly and a slip ring electrically coupling the stationary assembly and the rotating assembly. The rotating assembly may include one or more image sensors to capture one or more images and/or videos and generate an output signal corresponding to the captured images and/or videos. The rotating assembly may further include a first processing element configured to control operation of the image sensors. The stationary assembly may include a multi-axis inertial sensor to generate inertial data related to movements of the camera head, and may further include a second processing element configured to receive and process the output signal from of the image sensors and the inertial data from the multi-axis inertial sensor, to generate information pertaining to a pipe or cavity.

According to another aspect, a pipe inspection and/or mapping system is disclosed that may include a motion tracking camera head to generate a video signal representing real time or near real time images of scenes from the inside of a pipe and inertial data relating to measured positions or related aspects of the camera head and movements thereof. The system may further include a cable storage drum (interchangeably referred to as a drum reel) rotatably mounted on a support frame and a resilient, flexible push cable having a conductive element for communicating video

and data signals to and from the camera head operatively connected to a distal end of the push cable and to and from a central hub of the drum reel operatively connected to a proximal end of the push cable. The push cable may be stored in continuous turns on the drum reel, to be unwound and dispensed from the drum reel to force the camera head a substantial distance down a length of the pipe. A cable counting element may be provided to generate cable counting data measuring the distance of the push cable distributed out of the drum reel. A processing element may be disposed in one or more system devices for receiving at least the inertial data and cable counting data and generating control signals and output data from methods associated with corrected inertial data and pipe mapping. A non-transitory computer-readable memory may be disposed in one or more system devices for storing video and non-video data as well as associated output data. The system may further include a display element for displaying real time or post processed video or still images and other system and camera head data.

In another aspect, a motion tracking camera head is disclosed that may include an outer housing having a hollow interior in which a camera module assembly may be disposed. The camera module may include one or more image sensors for generating a video signal representing real time or near real time images of scenes in view of the image sensor(s). The camera head may include an illumination element configured to illuminate the field of view of the one or more image sensors. A multi-axis inertial sensor including at least one nine-axis sensor, may be disposed in the camera head, comprising at least accelerometers, magnetometers, and gyroscopic sensors measuring in three dimensions and configured to generate inertial data relating to measured positions or related aspects of the camera head and movements thereof. The camera head may further include a processing element to receive video signals, inertial data, and other non-video data which may include instructions from one or more directly or indirectly wired or wirelessly coupled system devices and perform operations relating to received instructions as well as received video signals and other data and generate related output video and non-video data signals that include the inertial data as well as command signals for controlling aspects of the camera head and other system devices.

In another aspect, a self-leveling motion tracking camera head is disclosed that may include an outer housing having a hollow interior in which a camera module assembly may be disposed. The camera module assembly may include a rotating assembly and a stationary assembly. The rotating assembly may be weighted along one side to be rotatable relative to the outer housing and contain one or more image sensors for generating a video signal that includes video and still image data corresponding to an interior of a pipe. The stationary assembly may be disposed inside and movable relative to the outer housing, comprising at least one nine-axis sensor comprising at least accelerometers, magnetometers, and gyroscopic sensors measuring in three dimensions configured to generate inertial data relating to measured positions or related aspects of the camera head and movements thereof. The stationary assembly may further include a processing element to receive video signals, inertial data, and other non-video data which may include instructions from one or more directly or indirectly wired or wirelessly coupled system devices and perform operations relating to received instructions as well as received video signal and other data and generate related output video and non-video data signals that include the inertial data as well as command signals for controlling aspects of the camera head and other system devices. The self-leveling motion tracking camera head may further include a slip ring electrically coupling the stationary assembly and the rotating assembly.

In another aspect, another self-leveling motion tracking camera head is disclosed that may include an outer housing having a hollow interior in which a camera module assembly may be disposed. The camera module assembly may include a rotating assembly and a stationary assembly. The rotating assembly may be weighted along one side to be rotatable relative to the outer housing and contain one or more image sensors for generating a video signal that includes video and still image data corresponding to an interior of a pipe. The rotating assembly may further include a first processing element configured to control aspects of the image sensor and/or video signal to enhance output video signals.

The stationary assembly may be disposed inside and movable relative to the outer housing, comprising at least one nine-axis sensor comprising at least accelerometers, magnetometers, and gyroscopic sensors measuring in three dimensions configured to generate inertial data relating to measured positions or related aspects of the camera head and movements thereof. The stationary assembly may further include a second processing element to receive video signals, inertial data, and other non-video data which may include instructions from one or more directly or indirectly wired or wirelessly coupled system devices and perform operations relating to received instructions as well as received video signal and other data and generate related output video and non-video data signals that include the inertial data as well as command signals for controlling aspects of the camera head and other system devices. The self-leveling motion tracking camera head may further include a slip ring electrically coupling the stationary assembly and the rotating assembly.

In another aspect, an inertial data correction and pipe mapping method is disclosed. The method may include determining the location of the access point of the camera head into a pipe and determining the direction of the camera head. The method may further include moving the camera head forward through the pipe while simultaneously determining push cable count data representing the length of push cable dispensed from the drum reel and outgoing inertial navigation data generated at the camera head. The method may further include moving the camera head through the pipe in the reverse direction while simultaneously determining push cable count data representing the length of data collected back into the drum reel and ingoing inertial navigation data generated at the camera head. Outgoing inertial navigation data and ingoing inertial navigation data may be correlated from the push cable count data. The method may include generating corrected inertial data based on correlating outgoing and ingoing inertial data. Optionally, a pipe map based on corrected inertial navigation data may be generated in another step. In a further optional step, the pipe map may be correlated to ground surface locations based on the access point location and directions from prior steps.

In another aspect, a method of depth from defocus for pipe inspection systems is disclosed. The method includes turning on the system, moving the camera head inside a pipe or other void while generating images of the inspection area and simultaneously determining a motion metric for the camera head, and performing depth from defocus during the inspection wherein the motion metric indicates the camera head is stationary or near stationary to within a predetermined threshold.

In another aspect, a method of depth from defocus for pipe inspection systems is disclosed. The method includes turning on the inspection system, moving the camera head inside a pipe or other void while generating images of the inspection area and simultaneously determining a motion metric for the camera head, and performing depth from defocus during the inspection wherein the motion metric indicates the camera head is stationary or near stationary to within a predetermined threshold.

In another aspect, a method for determining pipe and inspection parameters from an inspection system including audio exciter devices is disclosed. The method includes turning on the inspection system that includes a camera head having one or more microphones, moving the camera head inside a pipe while measuring and recording audio signals broadcast by one or more acoustic exciter devices, comparing the spectral signature of the audio signals against a database of audio signal spectral signatures to various pipe and inspection parameters, and determine a best fit match for the spectral signature in database to that received by the microphone(s). In another aspect, a method for alerting and/or avoiding pipe damage with a pipe inspection system having a camera head with one or more microphones. The method includes turning on the inspection system that includes a camera head having one or more microphones, moving the camera head inside a pipe while measuring and recording audio signals generated by the excavation process, comparing the audio signals against a database to determine potential danger to the pipe, and generating alerts to the user/excavator and/or actuating a kill switch to automate turning off of the excavation tools upon identifying danger to the pipe.

In another aspect, a method for controlling auto white balance (AWB) in a pipe inspection system. The method includes turning on the pipe inspection system that includes a camera head having a first AWB setting, continuing with the inspection until the pipe inspection system reaches a configured parameter limit relating to the AWB of the image sensors, and switching the camera head to a second AWB setting.

Various additional aspects, features, devices, systems, and functionality are further described below in conjunction with the appended Drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The present application may be more fully appreciated in connection with the following detailed description taken in conjunction with the accompanying Drawings, wherein:

FIG. **1**A is an illustration of a pipe inspection and mapping system embodiment in accordance with certain aspects.

FIG. **1**B is a diagram describing aspects of the motion tracking camera head from FIG. **1**A.

FIG. **2**A is another illustration of a pipe inspection and mapping system embodiment.

FIG. **2**B is a diagram describing aspects of the pipe inspection and mapping system embodiment from FIG. **2**A.

FIG. **3** is a corrected inertial data and pipe mapping method.

FIG. **4** is an illustration of a pipe inspection and mapping operation.

FIG. **5** is a diagram of a self-leveling motion tracking camera head.

FIG. **6** is a diagram of another self-leveling motion tracking camera head.

FIG. **7**A is an isometric view of a self-leveling motion tracking camera head embodiment.

FIG. **7**B is a partially exploded view of the camera head from FIG. **7**A.

FIG. **7**C is another partially exploded view of the camera head from FIG. **7**A.

FIG. **8**A is an exploded view of a camera module of the self-leveling motion tracking camera head embodiment of FIG. **7**A.

FIG. **8**B is another exploded view of a camera module of the self-leveling motion tracking camera head embodiment of FIG. **7**A.

FIG. **9**A is an exploded view of the rotating assembly.

FIG. **9**B is another exploded view of the rotating assembly.

FIG. **10** is a section view of the camera head from FIG. **7**A along line **10**-**10**.

FIG. **11** is an illustration of a camera head with ranging sensors.

FIG. **12** is a diagram of a camera head having one or more ranging sensors.

FIG. **13** is a method for depth from defocus for pipe inspection systems.

FIG. **14** is an illustration of a pipe inspection system with acoustic exciter devices.

FIG. **15** is a method for determining pipe and inspection parameters from a pipe inspection system with acoustic exciter devices.

FIG. **16** is a method for alerting and/or avoiding pipe damage with a pipe inspection system having a camera head with one or more microphones.

FIG. **17**A is an isometric view of a camera head with a push cable spring attached.

FIG. **17**B is a section view of the camera head and push cable spring from FIG. **17**A along line **17**B-**17**B.

FIG. **18** is a diagram describing aspects of another pipe inspection and mapping system embodiment.

FIG. **19**A is an illustration of a camera head, push cable spring, and push cable assembly with an optical lace system.

FIG. **19**B is a section view of the assembly from FIG. **19**A along line **19**B-**19**B.

FIG. **20** is an illustration of a camera head, optical lace system, and push cable assembly there the optical lace system functions as a push cable spring.

FIG. **21** is a diagram describing aspects of another pipe inspection and mapping system embodiment.

FIG. **22**A is an illustration of a camera head, push cable spring, and push cable assembly.

FIG. **22**B is a section view of the assembly from FIG. **22**A along line **22**A/B-**22**A/B demonstrating relative alignment of spatial separated inertial sensors when the assembly is straightened.

FIG. **22**C is a section view of the assembly from FIG. **22**A along line **22**A/B-**22**A/B demonstrating relative alignment of spatial separated inertial sensors when the assembly is bent.

FIG. **23** is a diagram describing aspects of another pipe inspection and mapping system embodiment.

FIG. **24** is a method for pipe mapping including the use of various inertial sensors.

FIG. **25** is a method for controlling automatic white balance (AWB) in a pipe inspection system.

DESCRIPTION OF EMBODIMENTS

Overview

This disclosure relates generally to camera heads and pipe inspection and/or mapping systems and methods used to inspect and/or map the interior of pipes and other conduits, cavities or voids. More specifically, but not exclusively, this disclosure relates to pipe inspection and mapping camera heads, including high dynamic range camera heads, as used in pipe inspection and mapping systems and methods for enhanced inertial data and improved pipe mapping.

According to one aspect, a pipe inspection and mapping system is disclosed including a motion tracking camera head configured for generating a video signal representing real time or near real time images of scenes from the inside of a pipe and inertial data relating to measured positions or related aspects of the camera head and movements thereof. The pipe inspection system includes a drum reel rotatably mounted on a support frame and a resilient, flexible push cable having a conductive element for communicating video and data signals to and from the camera head, operatively connected to a distal end of the push cable, and to and from a central hub of the drum reel operatively connected to a proximal end of the push cable wherein the push cable may be stored in continuous turns on the drum reel to be unwound and dispensed from the drum reel to force the camera head a substantial distance down a length of pipe. A cable counting element may generate cable counting data measuring the distance of the push cable distributed out of the drum reel. A processing element may be disposed in one or more system devices for receiving at least the inertial data and cable counting data and generating control signals and output data from methods associated with corrected inertial data and pipe mapping. A computer-readable memory may be disposed in one or more system devices for storing video and non-video data as well as associated output data. The pipe mapping system may further include a display element for displaying real time or post processed video or still images and other system and camera head data.

According to another aspect, the pipe inspection and mapping system may include various other system devices either directly or wirelessly coupled. For instance, the system may include one or more buried utility locator devices configured to receive electromagnetic field signals emitted from a hidden or buried conductor and/or Sonde device so as to determine and map the locations of the electromagnetic signal and associated source therefrom at the ground surface. The system may include one or more tracked rangefinder devices configured to generate imagery of geolocations on the Earth's surface having coordinates in a world coordinate system. A camera control unit (CCU) may be included in the system operatively coupled to the central hub of the drum reel to display and store video or other images representing the interior of the pipe, as well as display, process, and/or store inertial data and/or other non-video data. The system may include one or more remotely or directly coupled smart phones, tablets, laptops, data server computers, and/or other computing devices to display and store video or other images representing the interior of the pipe as well as display, process, and/or store inertial data and/or other non-video data. In the various devices (e.g., in the CCU, utility locating devices, drum reel, computing devices, or the like), WiFi, Bluetooth, and/or other wireless transceiver modules may communicate video/image, inertial, and/or other data for processing, storage, and/or display purposes.

In another aspect, the system may include a Sonde device at a known location relative to the camera head configured to broadcast an electromagnetic signal measurable at a utility locator device to determine the corresponding ground level location of the Sonde device. The Sonde may be disposed along the push cable at a known distance from the camera head and/or disposed in the camera head and may be a multi-frequency device. In some applications, the Sonde device may broadcast signal(s) at various distinct points during the pipe inspection that may be measured at a corresponding ground surface location via a utility locating device. The broadcasts signal(s) at various distinct points during the pipe inspection may be measured at a corresponding ground surface location via a utility locating device wherein each broadcast signal of each distinct point may have a unique frequency or signature.

In according to another, the various system devices may include one or more global navigation satellite system (GNSS) receivers to determine location(s) in a world coordinate system. For instance, GNSS receivers may be global positioning satellite (GPS) receivers disposed in the utility locator device, CCU, drum reel, and/or other system device. Likewise, the system may include one or more GPS backpack devices.

In another aspect, the system may be configured to generate corrected inertial data from inertial data generated from outgoing movements of the camera head correlating to ingoing movement of the camera head during a pipe inspection. The system may further generate a pipe map from the corrected inertial data of the camera head. The system may further correlate the pipe map location to locations at the ground surface.

In another aspect, the system may further include an in-pipe accessory device that may communicate with the camera head through receiving and transmitting a modulated light signal. The accessory may, for example, be a grasping tool for grasping objects which may be inside the pipe, separate Sonde device, a crawler device to aid in navigating the camera head through turns in the pipe, a pipe clearing device configured to remove debris or other unwanted items inside the pipe, or the like.

In another aspect, a motion tracking camera head is disclosed that may include an outer housing having a hollow interior in which a camera module assembly may be disposed. The camera module may including one or more image sensors for generating a video signal representing real time or near real time images of scenes in view of the image sensor(s). The camera head may include an illumination element configured to illuminate the field of view of the one or more image sensors. At least one nine-axis sensor may be included in the camera head comprising at least accelerometers, magnetometers, and gyroscopic sensors measuring in three dimensions and configured to generate inertial data relating to measured positions or related aspects of the camera head and movements thereof. The camera head may further include a processing element to receive video signals, inertial data, and other non-video data which may include instructions from one or more directly or indirectly wired or wirelessly coupled system devices and performing operations relating to received instructions as well as received video signal and other data and generating related output video and non-video data signals that includes the inertial data as well as command signals for controlling aspects of the camera head and other system devices.

In another aspect, a self-leveling motion tracking camera head is disclosed that may include an outer housing having a hollow interior in which a camera module assembly may be disposed. The camera module assembly may include a rotating assembly and a stationary assembly. The rotating assembly may be weighted along one side to be rotatable relative to the outer housing and contain one or more image sensors for generating video signal that includes video and still image data corresponding to an interior of a pipe. The stationary assembly may be disposed inside and movable relative to the outer housing comprising at least one nine-axis sensor comprising at least accelerometers, magnetometers, and gyroscopic sensors measuring in three dimensions configured to generate inertial data relating to measured positions or related aspects of the camera head and movements thereof. The stationary assembly may further include a processing element to receive video signals, inertial data, and other non-video data which may include instructions from one or more directly or indirectly wired or wirelessly coupled system devices and performing operations relating to received instructions as well as received video signal and other data and generating related output video and non-video data signals that includes the inertial data as well as command signals for controlling aspects of the camera head and other system devices. The self-leveling motion tracking camera head may further include a slip ring electrically coupling the stationary assembly and the rotating assembly.

In another aspect, another self-leveling motion tracking camera head is disclosed that may include an outer housing having a hollow interior in which a camera module assembly may be disposed. The camera module assembly may include a rotating assembly and a stationary assembly. The rotating assembly may be weighted along one side to be rotatable relative to the outer housing and contain one or more image sensors for generating video signal that includes video and still image data corresponding to an interior of a pipe. The rotating assembly may further include a first processing element configured to control aspects of the image sensor and/or video signal to enhance output video signal. The stationary assembly may be disposed inside and movable relative to the outer housing comprising at least one nine-axis sensor comprising at least accelerometers, magnetometers, and gyroscopic sensors measuring in three dimensions configured to generate inertial data relating to measured positions or related aspects of the camera head and movements thereof. The stationary assembly may further include a second processing element to receive video signals, inertial data, and other non-video data which may include instructions from one or more directly or indirectly wired or wirelessly coupled system devices and performing operations relating to received instructions as well as received video signal and other data and generating related output video and non-video data signals that includes the inertial data as well as command signals for controlling aspects of the camera head and other system devices. The self-leveling motion tracking camera head may further include a slip ring electrically coupling the stationary assembly and the rotating assembly.

In another aspect, the motion tracking camera heads may have high dynamic range (HDR) or auto HDR image sensors. In some second embodiments, a processing element may be configured to generate HDR video and images. Such embodiments may use inertial data as a metric in generating HDR video and images.

In another aspect, the motion tracking camera heads may include one or more Sondes disposed in the camera heads which may be multi-frequency Sondes.

In another aspect, the camera head may include a variety of other sensors. For instance, the camera head may include a temperature sensor configured to measure camera head temperature, a humidity sensor configured to measure humidity inside the camera head, and/or one or more distance ranging sensors configured to measure distance to aspects in the pipe viewed by the image sensor(s).

In another aspect, the camera head may be configured to modulate the light emitted by the illumination module. The modulation of the illumination element may be used to transmit data with an in-pipe accessory device. The camera head may, likewise, be configured to receive, interpret, and perform operations relating to transmitted data in the form of modulated light from an in-pipe accessory device.

In another aspect, an inertial data correction and pipe mapping method is disclosed. The method may include determining the location of the access point of the camera head into a pipe and determining the direction of the camera head. The method may further include moving the camera head forward through the pipe while simultaneously determining push cable count data representing the length of push cable dispensed from the drum reel and outgoing inertial navigation data generated at the camera head. The method may further include moving the camera head through the pipe in the reverse direction while simultaneously determining push cable count data representing the length of data collected back into the drum reel and ingoing inertial navigation data generated at the camera head. Outgoing inertial navigation data and ingoing inertial navigation data may be correlated from the push cable count data. The method may include generating corrected inertial data based on correlating outgoing and ingoing inertial data. Optionally, a pipe map based on corrected inertial navigation data may be generated in another step. In a further optional step, the pipe map may be correlated to ground surface locations based on the access point location and directions from prior steps.

In another aspect, access point location where the camera head enters a pipe at the ground surface may be determined. For instance, access point location may be determined by GPS, by a user and input into the pipe mapping system, identified and photographed by a tracked distance measuring device, the camera head may automatically identify the access point location, and/or like device or technique to determine locations in a world coordinate system.

In another aspect, the direction of the camera head may be determined, for instance, by compass sensor data at the camera head, determined by location points along the ground surface, or the like. In some embodiments, compass data may be corrected or improved by known location points at the ground surface.

In another aspect, the mapping of utility lines may include camera heads and assemblies and systems including camera heads having various sensors and apparatus to determine bend and turns in pipes or like conduits in both degree and direction. For instance, at one embodiment in keeping with the present disclosure may include a camera head or assembly including a camera head (e.g., assembly further including a push cable and/or push cable spring) which may include one or more strain gauges to measure the degree and direction of bends and turns in the pipe as the assembly is moved through. Likewise, at least one embodiment may include an assembly having a series of spatially separated inertial sensors with known orientations wherein the degree and direction of bends and turns in the pipe are measured and mapped via changes in the alignment of the inertial sensors as the assembly is moved through the bends and turns. In at least one embodiment in keeping with the present disclosure, the measuring and mapping of bends and turns may be achieved via an optical lace system. Such an optical lace system may have a deformable lattice structure embedded with optical fibers or similar optical pathways to interpret the movement of the lattice structure via changes in light determined at a number of light sensors and wherein the movements of the lattice structure are interpreted as movements of the camera head assembly through bends and turns in a pipe for purposes of mapping. In some embodiments, the optical lace system may function as a push cable spring providing improved handling and control in moving the camera head and assembly through the pipe or other conduit. For instance, such an optical lace push cable spring may have various sections of differing stiffness to improve handling.

In another aspect, the push cable springs of the various embodiments herein may be 3D printed. For instance, in embodiments having an optical lace push cable spring, 3D printing process may allow for the resolution to form the intricate lattice structure of the optical lace push cable spring. Likewise, a 3D printing process may be used to form other push cable springs. In such embodiments, the 3D printing process may allow for low cost push cable springs having intricate details and unique mechanical properties.

In another aspect, a method of depth from defocus for pipe inspection systems is disclosed. The method includes turning on the system, moving the camera head inside a pipe or other void while generating images of the inspection area and simultaneously determining a motion metric for the camera head, and performing depth from defocus during the inspection wherein the motion metric indicates the camera head is stationary or near stationary to within a predetermined threshold.

In another aspect, a method of depth from defocus for pipe inspection systems is disclosed. The method includes turning on the inspection system, moving the camera head inside a pipe or other void while generating images of the inspection area and simultaneously determining a motion metric for the camera head, and performing depth from defocus during the inspection wherein the motion metric indicates the camera head is stationary or near stationary to within a predetermined threshold.

In another aspect, a method for determining pipe and inspection parameters from an inspection system including audio exciter devices is disclosed. The method includes turning on the inspection system that includes a camera head having one or more microphones, moving the camera head inside a pipe while measuring and recording audio signals broadcast by one or more acoustic exciter devices, comparing the spectral signature of the audio signals against a database of audio signal spectral signatures to various pipe and inspection parameters, and determine a best fit match for the spectral signature in database to that received by the microphone(s). In another aspect, a method for alerting and/or avoiding pipe damage with a pipe inspection system having a camera head with one or more microphones. The method includes turning on the inspection system that includes a camera head having one or more microphones, moving the camera head inside a pipe while measuring and recording audio signals generated by the excavation process, comparing the audio signals against a database to determine potential danger to the pipe, and generating alerts to the user/excavator and/or actuating a kill switch to automate turning off of the excavation tools upon identifying danger to the pipe.

In another aspect, a method for controlling auto white balance (AWB) in a pipe inspection system. The method includes turning on the pipe inspection system that includes a camera head having a first AWB setting, continuing with the inspection until the pipe inspection system reaches a configured parameter limit relating to the AWB of the image sensors, and switching the camera head to a second AWB setting. The first AWB setting is optimized for viewing the external environment before entering the pipe. For instance, the first AWB setting may turn off AWB. The configured parameter limit may be or include a time setting from turning on the system, is related to push cable count provided by a cable counter element, and/or is related to a motion metric of the camera head. The second AWB setting may be optimized for viewing the internal environment in the pipe. For instance, the second AWB setting may have the AWB turned on.

Various aspects of pipe inspection and/or mapping systems, apparatus, devices, configurations and methods that may be used in conjunction with the details herein of various embodiments are described in co-assigned patents and patent applications including: U.S. Pat. No. 6,545,704, issued Apr. 7, 1999, entitled VIDEO PIPE INSPECTION DISTANCE MEASURING SYSTEM; U.S. Pat. No. 5,939,679, issued Aug. 17, 1999, entitled VIDEO PUSH CABLE; U.S. Pat. No. 6,831,679, issued Dec. 14, 2004, entitled VIDEO CAMERA HEAD WITH THERMAL FEEDBACK LIGHTING CONTROL; U.S. Pat. No. 6,862,945, issued Mar. 8, 2005, entitled CAMERA GUIDE FOR VIDEO PIPE INSPECTION SYSTEM; U.S. Pat. No. 6,908,310, issued Jun. 21, 2005, entitled SLIP RING ASSEMBLY WITH INTEGRAL POSITION ENCODER; U.S. Pat. No. 6,958,767, issued Oct. 25, 2005, entitled VIDEO PIPE INSPECTION SYSTEM EMPLOYING NON-ROTATING CABLE STORAGE DRUM; U.S. Pat. No. 7,009,399, issued Mar. 7, 2006, entitled OMNIDIRECTIONAL SONDE AND LINE LOCATOR; U.S. Pat. No. 7,136,765, issued Nov. 14, 2006, entitled A BURIED OBJECT LOCATING AND TRACING METHOD AND SYSTEM EMPLOYING PRINCIPAL COMPONENTS ANALYSIS FOR BLIND SIGNAL DETECTION; U.S. Pat. No. 7,221,136, issued May 22, 2007, entitled SONDES FOR LOCATING UNDERGROUND PIPES AND CONDUITS; U.S. Pat. No. 7,276,910, issued Oct. 2, 2007, entitled A COMPACT SELF-TUNED ELECTRICAL RESONATOR FOR BURIED OBJECT LOCATOR APPLICATIONS; U.S. Pat. No. 7,288,929, issued Oct. 30, 2007, entitled INDUCTIVE CLAMP FOR APPLYING SIGNAL TO BURIED UTILITIES; U.S. Pat. No. 7,298,126, issued Nov. 20, 2007, entitled SONDES FOR LOCATING UNDERGROUND PIPES AND CONDUITS; U.S. Pat. No. 7,332,901, issued Feb. 19, 2008, entitled LOCATOR WITH APPARENT DEPTH INDICATION; U.S. Pat. No. 7,336,078, issued Feb. 26, 2008, entitled MULTI-SENSOR MAPPING OMNIDIRECTIONAL SONDE AND LINE LOCATORS; U.S. Pat. No. 7,443,154, issued Oct. 28, 2008, entitled MULTI-SENSOR MAPPING OMNIDIRECTIONAL SONDE AND LINE LOCATOR; U.S. Pat. No. 7,498,797, issued Mar. 3, 2009, entitled LOCATOR WITH CURRENT-MEASURING CAPABILITY; U.S. Pat. No. 7,498,816, issued Mar. 3, 2009, entitled OMNIDIRECTIONAL SONDE AND LINE LOCATOR; U.S. Pat. No. 7,518,374, issued Apr. 14, 2009, entitled RECONFIGURABLE PORTABLE LOCATOR EMPLOYING MULTIPLE SENSOR ARRAYS HAVING FLEXIBLE NESTED ORTHOGONAL ANTENNAS; U.S. Pat. No. 7,557,559, issued Jul. 7, 2009, entitled COMPACT LINE ILLUMINATOR FOR LOCATING BURIED PIPES AND CABLES; U.S. Pat. No. 7,619,516, issued Nov. 17, 2009, entitled SINGLE AND MULTI-TRACE OMNIDIRECTIONAL SONDE AND LINE LOCATORS AND TRANSMITTER USED THEREWITH; U.S. patent application Ser. No. 12/704,808, now U.S. Pat. No. 10,009,582, filed Feb. 12, 2010, entitled PIPE INSPECTION SYSTEM WITH REPLACEABLE CABLE STORAGE DRUM; U.S. Pat. No. 7,733,077, issued Jun. 8, 2010, entitled MULTI-SENSOR MAPPING OMNIDIRECTIONAL SONDE AND LINE LOCATORS AND TRANSMITTER USED THEREWITH; U.S. Pat. No. 7,741,848, issued Jun. 22, 2010, entitled ADAPTIVE MULTICHANNEL LOCATOR SYSTEM FOR MULTIPLE PROXIMITY DETECTION; U.S. Pat. No. 7,755,360, issued Jul. 13, 2010, entitled PORTABLE LOCATOR SYSTEM WITH JAMMING REDUCTION; U.S. Pat. No. 7,825,647, issued Nov. 2, 2010, entitled METHOD FOR LOCATING BURIED PIPES AND CABLES; U.S. Pat. No. 7,830,149, issued Nov. 9, 2010, entitled AN UNDERGROUND UTILITY LOCATOR WITH A TRANSMITTER A PAIR OF UPWARDLY OPENING POCKETS AND HELICAL COIL TYPE ELECTRICAL CORDS; U.S. Pat. No. 7,863,885, issued Jan. 4, 2011, entitled SONDES FOR LOCATING UNDERGROUND PIPES AND CONDUITS; U.S. Pat. No. 7,948,236, issued May 24, 2011, entitled ADAPTIVE MULTICHANNEL LOCATOR SYSTEM FOR MULTIPLE PROXIMITY DETECTION; U.S. Pat. No. 7,969,419, issued Jun. 28, 2011, entitled PRE-AMPLIFIER AND MIXER CIRCUITRY FOR A LOCATOR ANTENNA; U.S. patent application Ser. No. 13/189,844, filed Jul. 25, 2011, entitled BURIED OBJECT LOCATOR SYSTEMS AND METHODS; U.S. Pat. No. 7,990,151, issued Aug. 2, 2011, entitled TRI-POD BURIED LOCATOR SYSTEM; U.S. Pat. No. 8,013,610, issued Sep. 6, 2011, entitled HIGH Q SELF-TUNING LOCATING TRANSMITTER; U.S. Pat. No. 8,035,390, issued Oct. 11, 2011, entitled OMNIDIRECTIONAL SONDE AND LINE LOCATOR; U.S. patent application Ser. No. 13/346,668, now U.S. Pat. No. 10,001,425, filed Jan. 9, 2012, entitled PORTABLE CAMERA CONTROLLER PLATFORM FOR USE WITH PIPE INSPECTION SYSTEM; U.S. Pat. No. 8,106,660, issued Jan. 31, 2012, entitled SONDE ARRAY FOR USE WITH BURIED LINE LOCATOR; U.S. Pat. No. 8,203,343, issued Jun. 19, 2012, entitled RECONFIGURABLE PORTABLE LOCATOR EMPLOYING MULTIPLE SENSOR ARRAYS HAVING FLEXIBLE NESTED ORTHOGONAL ANTENNAS; U.S. patent application Ser. No. 13/584,799, filed Aug. 13, 2012, entitled BURIED OBJECT LOCATOR SYSTEMS AND METHODS; U.S. Pat. No. 8,248,056, issued Aug. 21, 2012, entitled A BURIED OBJECT LOCATOR SYSTEM EMPLOYING AUTOMATED VIRTUAL DEPTH EVENT DETECTION AND SIGNALING; U.S. Pat. No. 8,264,226, issued Sep. 11, 2012, entitled SYSTEMS AND METHODS FOR LOCATING BURIED PIPES AND CABLES WITH A MAN PORTABLE LOCATOR AND A TRANSMITTER IN A MESH NETWORK; U.S. patent application Ser. No. 13/647,310, filed Oct. 8, 2012, entitled PIPE INSPECTION SYSTEM APPARATUS AND METHODS; U.S. Pat. No. 8,289,385, issued Oct. 16, 2012, entitled PUSH-CABLE FOR PIPE INSPECTION SYSTEM; U.S. patent application Ser. No. 13/769,202, filed Feb. 15, 2013, entitled SMART PAINT STICK DEVICES AND METHODS; U.S. patent application Ser. No. 13/774,351, now U.S. Pat. No. 10,371,305, filed Feb. 22, 2013, entitled DOCKABLE TRIPODAL CAMERA CONTROL UNIT; U.S. patent application Ser. No. 13/787,711, filed Mar. 6, 2013, entitled DUAL SENSED LOCATING SYSTEMS AND METHODS; U.S. patent application Ser. No. 13/793,168, filed Mar. 11, 2013, entitled BURIED OBJECT LOCATORS WITH CONDUCTIVE ANTENNA BOBBINS; U.S. Pat. No. 8,395,661, issued Mar. 12, 2013, entitled PIPE INSPECTION SYSTEM WITH SELECTIVE IMAGE CAPTURE; U.S. patent application Ser. No. 13/826,112, filed Mar. 14, 2013, entitled SYSTEMS AND METHODS INVOLVING A SMART CABLE STORAGE DRUM AND NETWORK NODE FOR TRANSMISSION OF DATA; U.S. Pat. No. 8,400,154, issued Mar. 19, 2013, entitled LOCATOR ANTENNA WITH CONDUCTIVE BOBBIN; U.S. patent application Ser. No. 13/851,951, filed Mar. 27, 2013, entitled DUAL ANTENNA SYSTEMS WITH VARIABLE POLARIZATION; U.S. patent application Ser. No. 13/894,038, now U.S. Pat. No. 10,042,072, filed May 14, 2013, entitled OMNI-INDUCER TRANSMITTING DEVICES AND METHODS; U.S. patent application Ser. No. 13/925,636, now U.S. Pat. No. 10,090,498, filed Jun. 24, 2013, entitled MODULAR BATTERY PACK APPARATUS, SYSTEMS, AND METHODS INCLUDING VIRAL DATA AND/OR CODE TRANSFER; U.S. patent application Ser. No. 14/027,027, filed Sep. 13, 2013, entitled SONDE DEVICES INCLUDING A SECTIONAL FERRITE CORE STRUCTURE; U.S. Pat. No. 8,547,428, issued Oct. 1, 2013, entitled PIPE MAPPING SYSTEM; U.S. Pat. No. 8,564,295, issued Oct. 22, 2013, entitled METHOD FOR SIMULTANEOUSLY DETERMINING A PLURALITY OF DIFFERENT LOCATIONS OF THE BURIED OBJECTS AND SIMULTANEOUSLY INDICATING THE DIFFERENT LOCATIONS TO A USER; U.S. patent application Ser. No. 14/033,349, filed Sep. 20, 2013, entitled PIPE INSPECTION WITH SNAP ON PIPE GUIDES; U.S. Pat. No. 8,540,429, issued Sep. 24, 2013, entitled SNAP ON PIPE GUIDE; U.S. patent application Ser. No. 14/077,022, now U.S. Pat. No. 10,024,994, filed Nov. 11, 2013, entitled WEARABLE MAGNETIC FIELD UTILITY LOCATOR SYSTEM WITH SOUND FIELD GENERATION; U.S. Pat. No. 8,587,648, issued Nov. 19, 2013, entitled SELF-LEVELING CAMERA HEAD; U.S. patent application Ser. No. 14/136,104, now U.S. Pat. No. 10,288,997, filed Dec. 20, 2013, entitled ROTATING CONTACT ASSEMBLIES FOR SELF-LEVELING CAMERA HEADS; U.S. patent application Ser. No. 14/148,649, filed Jan. 6, 2014, entitled MAPPING LOCATING SYSTEMS AND METHODS; U.S. Pat. No. 8,635,043, issued Jan. 21, 2014, entitled LOCATOR AND TRANSMITTER CALIBRATION SYSTEM; U.S. patent application Ser. No. 14/203,485, filed Mar. 10, 2014, entitled PIPE INSPECTION CABLE COUNTER AND OVERLAY MANAGEMENT SYSTEM; U.S. patent application Ser. No. 14/207,527, filed Mar. 12, 2014, entitled ROTATING CONTACT ASSEMBLIES FOR SELF-LEVELING CAMERA HEADS; U.S. patent application Ser. No. 14/207,502, filed Mar. 12, 2014, entitled GRADIENT ANTENNA COILS FOR USE IN LOCATING SYSTEMS; U.S. patent application Ser. No. 14/214,151, filed Mar. 14, 2014, entitled DUAL ANTENNA SYSTEMS WITH VARIABLE POLARIZATION; U.S. patent application Ser. No. 14/216,358, filed Mar. 17, 2014, entitled SMART CABLE STORAGE DRUM AND NETWORK NODE SYSTEM AND METHODS; U.S. Pat. No. 8,717,028, issued May 6, 2014, entitled SPRING CLIPS FOR USE WITH LOCATING TRANSMITTERS; U.S. Pat. No. 8,773,133, issued Jul. 8, 2014, entitled ADAPTIVE MULTICHANNEL LOCATOR SYSTEM FOR MULTIPLE PROXIMITY DETECTION; U.S. Pat. No. 9,703,002, issued Jul. 13, 2014, entitled UTILITY LOCATOR SYSTEMS AND METHODS; U.S. patent application Ser. No. 14/446,145, now U.S. Pat. No. 10,274,632, filed Jul. 29, 2014, entitled UTILITY LOCATING SYSTEMS WITH MOBILE BASE STATION; U.S. Pat. No. 8,841,912, issued Sep. 23, 2014, entitled PRE-AMPLIFIER AND MIXER CIRCUITRY FOR A LOCATOR ANTENNA; U.S. patent application Ser. No. 14/935,878, now U.S. Pat. No. 10,440,332, filed Nov. 7, 2014, entitled INSPECTION CAMERA DEVICES AND METHODS WITH SELECTIVELY ILLUMINATED MULTISENSOR IMAGING; U.S. patent application Ser. No. 14/557,163, now U.S. Pat. No. 10,024,366, filed Dec. 1, 2014, entitled ASSYMETRIC DRAG FORCE BEARING; U.S.

Pat. No. 8,908,027, issued Dec. 9, 2014, entitled ASYMMETRIC DRAG FORCE BEARING FOR USE WITH PUSH-CABLE STORAGE DRUM; U.S. Pat. No. 8,970,211, issued Mar. 3, 2015, entitled PIPE INSPECTION CABLE COUNTER AND OVERLAY MANAGEMENT SYSTEM; U.S. patent application Ser. No. 14/642,596, now U.S. Pat. No. 10,100,507, filed Mar. 9, 2015, entitled PIPE CLEARING CABLES AND APPARATUS; U.S. Pat. No. 8,984,698, issued Mar. 24, 2015, entitled LIGHT WEIGHT SEWER CABLE; U.S. patent application Ser. No. 14/709,301, filed May 11, 2015, entitled PIPE MAPPING SYSTEMS AND METHODS; U.S. Pat. No. 9,041,794, issued May 26, 2015, entitled PIPE MAPPING SYSTEMS AND METHODS; U.S. Pat. No. 9,057,754, issued Jun. 16, 2015, entitled ECONOMICAL MAGNETIC LOCATOR APPARATUS AND METHOD; U.S. patent application Ser. No. 14/746,590, now U.S. Pat. No. 10,171,712, filed Jun. 22, 2015, entitled THERMAL EXTRACTION ARCHITECTURES FOR CAMERA AND LIGHTING DEVICES; U.S. Pat. No. 9,066,446, issued Jun. 23, 2015, entitled THERMAL EXTRACTION ARCHITECTURE FOR CAMERA HEADS, INSPECTION SYSTEMS, AND OTHER DEVICES AND SYSTEMS; U.S. patent application Ser. No. 14/749,545, now U.S. Pat. No. 10,175,177, filed Jun. 24, 2015, entitled ADJUSTABLE VARIABLE RESOLUTION INSPECTION SYSTEMS AND METHODS; U.S. patent application Ser. No. 14/797,760, filed Jul. 13, 2015, entitled HAPTIC DIRECTIONAL FEEDBACK HANDLES FOR LOCATING DEVICES; U.S. patent application Ser. No. 14/798,177, now U.S. Pat. No. 10,059,504, filed Jul. 13, 2015, entitled MARKING PAINT APPLICATOR FOR USE WITH PORTABLE UTILITY LOCATOR; U.S. Pat. No. 9,081,109, issued Jul. 14, 2015, entitled GROUND-TRACKING DEVICES FOR USE WITH A MAPPING LOCATOR; U.S. Pat. No. 9,082,269, issued Jul. 14, 2015, entitled HAPTIC DIRECTIONAL FEEDBACK HANDLES FOR LOCATION DEVICES; U.S. Pat. No. 9,080,992, issued Jul. 14, 2015, entitled ADJUSTABLE VARIABLE RESOLUTION INSPECTION SYSTEMS AND METHODS; U.S. patent application Ser. No. 14/800,490, filed Jul. 15, 2013, entitled UTILITY LOCATOR DEVICES, SYSTEMS, AND METHODS WITH SATELLITE AND MAGNETIC FIELD SONDE ANTENNA SYSTEMS; U.S. Pat. No. 9,085,007, issued Jul. 21, 2015, entitled MARKING PAINT APPLICATOR FOR PORTABLE LOCATOR; U.S. Pat. No. 9,134,255, issued Sep. 15, 2015, entitled PIPE INSPECTION SYSTEM WITH SELECTIVE IMAGE CAPTURE; U.S. patent application Ser. No. 14/949,868, now U.S. Pat. No. 10,078,149, filed Nov. 23, 2015, entitled BURIED OBJECT LOCATORS WITH DODECAHEDRAL ANTENNA NODES; U.S. Pat. No. 9,207,350, issued Dec. 8, 2015, entitled BURIED OBJECT LOCATOR APPARATUS WITH SAFETY LIGHTING ARRAY; U.S. patent application Ser. No. 14/970,362, filed Dec. 15, 2015, entitled COAXIAL VIDEO PUSH-CABLES FOR USE IN INSPECTION SYSTEMS; U.S. Pat. No. 9,222,809, issued Dec. 29, 2015, entitled PORTABLE PIPE INSPECTION SYSTEMS AND APPARATUS; U.S. patent application Ser. No. 15/006,119, now U.S. Pat. No. 10,353,103, filed Jan. 26, 2016, entitled SELF-STANDING MULTI-LEG ATTACHMENT DEVICES FOR USE WITH UTILITY LOCATORS; U.S. patent application Ser. No. 15/434,056, now U.S. Pat. No. 10,401,526, filed Feb. 16, 2016, entitled BURIED UTILITY MARKER DEVICES, SYSTEMS, AND METHODS; U.S. patent application Ser. No. 15/050,267, now U.S. Pat. No. 10,009,519, filed Feb. 22, 2016, entitled SELF-LEVELING CAMERA HEAD; U.S. Pat. No. 9,277,105, issued Mar. 1, 2016, entitled SELF-LEVELING CAMERA HEAD; U.S. Pat. No. 9,341,740, issued May 17, 2016, entitled OPTICAL GROUND TRACKING APPARATUS, SYSTEMS, AND METHODS; U.S. patent application Ser. No. 15/187,785, filed Jun. 21, 2016, entitled BURIED UTILITY LOCATOR GROUND TRACKING APPARATUS, SYSTEMS, AND METHODS; U.S. Pat. No. 9,372,117, issued Jun. 21, 2016, entitled OPTICAL GROUND TRACKING APPARATUS, SYSTEMS, AND METHODS; U.S. patent application Ser. No. 15/225,623, filed Aug. 1, 2016, entitled SONDE-BASED GROUND-TRACKING APPARATUS AND METHODS; U.S. patent application Ser. No. 15/225,721, filed Aug. 1, 2016, entitled SONDES AND METHODS FOR USE WITH BURIED LINE LOCATOR SYSTEMS; U.S. Pat. No. 9,411,066, issued Aug. 9, 2016, entitled SONDES AND METHODS FOR USE WITH BURIED LINE LOCATOR SYSTEMS; U.S. Pat. No. 9,411,067, issued Aug. 9, 2016, entitled GROUND-TRACKING SYSTEMS AND APPARATUS; U.S. patent application Ser. No. 15/247,503, filed Aug. 25, 2016, entitled LOCATING DEVICES, SYSTEMS, AND METHODS USING FREQUENCY SUITES FOR UTILITY DETECTION; U.S. Pat. No. 9,927,546, issued Aug. 29, 2016, entitled PHASE SYNCHRONIZED BURIED OBJECT LOCATOR APPARATUS, SYSTEMS, AND METHODS; U.S. Pat. No. 9,435,907, issued Sep. 6, 2016, entitled PHASE SYNCHRONIZED BURIED OBJECT LOCATOR APPARATUS, SYSTEMS, AND METHODS; U.S. patent application Ser. No. 15/264,355, now U.S. Pat. No. 10,356,360, filed Sep. 13, 2016, entitled HIGH BANDWIDTH VIDEO PUSH-CABLES FOR PIPE INSPECTION SYSTEMS; U.S. Pat. No. 9,448,376, issued Sep. 20, 2016, entitled HIGH BANDWIDTH PUSH-CABLES FOR VIDEO PIPE INSPECTION SYSTEMS; U.S. Pat. No. 9,465,129, issued Oct. 11, 2016, entitled IMAGE-BASED MAPPING LOCATING SYSTEM; U.S. Pat. No. 9,468,954, issued Oct. 18, 2016, entitled PIPE INSPECTION SYSTEM WITH JETTER PUSH-CABLE; U.S. patent application Ser. No. 15/331,570, now U.S. Pat. No. 10,073,186, filed Oct. 21, 2016, entitled KEYED CURRENT SIGNAL UTILITY LOCATING SYSTEMS AND METHODS; U.S. Pat. No. 9,477,147, issued Oct. 25, 2016, entitled SPRING ASSEMBLIES WITH VARIABLE FLEXIBILITY FOR USE WITH PUSH-CABLES AND PIPE INSPECTION SYSTEMS; U.S. patent application Ser. No. 15/339,766, now U.S. Pat. No. 10,031,253, filed Oct. 31, 2016, entitled GRADIENT ANTENNA COILS AND ARRAYS FOR USE IN LOCATING SYSTEMS; U.S. patent application Ser. No. 15/345,421, Nov. 7, 2016, entitled OMNI-INDUCER TRANSMITTING DEVICES AND METHODS; U.S. Pat. No. 9,488,747, issued Nov. 8, 2016, entitled GRADIENT ANTENNA COILS AND ARRAYS FOR USE IN LOCATING SYSTEM; U.S. Pat. No. 9,494,706, issued Nov. 15, 2016, entitled OMNI-INDUCER TRANSMITTING DEVICES AND METHODS; U.S. patent application Ser. No. 15/360,979, filed Nov. 23, 2016, entitled UTILITY LOCATING SYSTEMS, DEVICES, AND METHODS USING RADIO BROADCAST SIGNALS; U.S. patent application Ser. No. 15/369,693, now U.S. Pat. No. 10,084,945, filed Dec. 5, 2016, entitled CABLE STORAGE DRUM WITH MOVABLE CCU DOCKING APPARATUS; U.S. patent application Ser. No. 15/376,576, now U.S. Pat. No. 10,082,599, filed Dec. 12, 2016, entitled MAGNETIC SENSING BURIED OBJECT LOCATOR INCLUDING A CAMERA; U.S. Pat. No. 9,521,303, issued Dec. 13, 2016, entitled CABLE STORAGE DRUM WITH MOVEABLE CCU DOCKING

APPARATUS; U.S. Pat. No. 9,523,788, issued Dec. 20, 2016, entitled MAGNETIC SENSING BURIED OBJECT LOCATOR INCLUDING A CAMERA; U.S. patent application Ser. No. 15/396,068, now U.S. Pat. No. 10,247,845, filed Dec. 30, 2016, entitled UTILITY LOCATOR TRANSMITTER APPARATUS AND METHODS; U.S. patent application Ser. No. 15/425,785, now U.S. Pat. No. 10,027, 526, filed Feb. 6, 2017, entitled METHOD AND APPARATUS FOR HIGH-SPEED DATA TRANSFER EMPLOYING SELF-SYNCHRONIZING QUADRATURE AMPLITUDE MODULATION (QAM); U.S. Pat. No. 9,571,326, issued Feb. 14, 2017, entitled METHOD AND APPARATUS FOR HIGH-SPEED DATA TRANSFER EMPLOYING SELF-SYNCHRONIZING QUADRATURE AMPLITUDE MODULATION (QAM); U.S. patent application Ser. No. 15/457,149, filed Mar. 13, 2017, entitled USER INTERFACES FOR UTILITY LOCATORS; U.S. patent application Ser. No. 15/457,222, filed Mar. 13, 2017, entitled SYSTEMS AND METHODS FOR LOCATING BURIED OR HIDDEN OBJECTS USING SHEET CURRENT FLOW MODELS; U.S. patent application Ser. No. 15/457,897, now U.S. Pat. No. 10,162,074, filed Mar. 13, 2017, entitled UTILITY LOCATORS WITH RETRACTABLE SUPPORT STRUCTURES AND APPLICATIONS THEREOF; U.S. patent application Ser. No. 14/022,067, now U.S. Pat. No. 9,599,740, filed Mar. 21, 2017, entitled USER INTERFACES FOR UTILITY LOCATORS; U.S. Pat. No. 9,599,449, issued Mar. 21, 2017, entitled SYSTEMS AND METHODS FOR LOCATING BURIED OR HIDDEN OBJECTS USING SHEET CURRENT FLOW MODELS; U.S. patent application Ser. No. 15/470,642, filed Mar. 27, 2017, entitled UTILITY LOCATING APPARATUS AND SYSTEMS USING MULTIPLE ANTENNA COILS; U.S. patent application Ser. No. 15/470,713, filed Mar. 27, 2017, entitled UTILITY LOCATORS WITH PERSONAL COMMUNICATION DEVICE USER INTERFACES; U.S. patent application Ser. No. 15/483,924, now U.S. Pat. No. 10,069,667, filed Apr. 10, 2017, entitled SYSTEMS AND METHODS FOR DATA TRANSFER USING SELF-SYNCHRONIZING QUADRATURE AMPLITUDE MODULATION (QAM); U.S. patent application Ser. No. 15/485,082, now U.S. Pat. No. 10,082,591, filed Apr. 11, 2017, entitled MAGNETIC UTILITY LOCATOR DEVICES AND METHODS; U.S. patent application Ser. No. 15/485,125, now U.S. Pat. No. 10,088,592, filed Apr. 11, 2017, entitled INDUCTIVE CLAMP DEVICES, SYSTEMS, AND METHODS; U.S. Pat. No. 9,625,602, issued Apr. 18, 2017, entitled SMART PERSONAL COMMUNICATION DEVICES AS USER INTERFACES; U.S. patent application Ser. No. 15/497,040, filed Apr. 25, 2017, entitled SYSTEMS AND METHODS FOR LOCATING AND/OR MAPPING BURIED UTILITIES USING VEHICLE-MOUNTED LOCATING DEVICES; U.S. Pat. No. 9,632,199, issued Apr. 25, 2017, entitled INDUCTIVE CLAMP DEVICES, SYSTEMS, AND METHODS; U.S. Pat. No. 9,632,202, issued Apr. 25, 2017, entitled ECONOMICAL MAGNETIC LOCATOR APPARATUS AND METHOD; U.S. Pat. No. 9,634,878, issued Apr. 25, 2017, entitled SYSTEMS AND METHODS FOR DATA SYNCHRONIZING QUADRATURE AMPLITUDE MODULATION (QAM); U.S. Pat. No. 9,638,824, issued May 2, 2017, entitled QUAD-GRADIENT COILS FOR USE IN LOCATING SYSTEMS; U.S. patent application Ser. No. 15/590,964, filed May 9, 2017, entitled BORING INSPECTION SYSTEMS AND METHODS; U.S. Pat. No. 9,651, 711, issued May 16, 2017, entitled HORIZONTAL BORING INSPECTION DEVICE AND METHODS; U.S. patent application Ser. No. 15/623,174, now U.S. Pat. No. 10,105, 723, filed Jun. 14, 2017, entitled TRACKABLE DIPOLE DEVICES, METHODS, AND SYSTEMS FOR USE WITH MARKING PAINT STICKS; U.S. patent application Ser. No. 15/185,018, filed Jun. 17, 2016, entitled RESILIENTLY DEFORMABLE MAGNETIC FIELD TRANSMITTER CORES FOR USE WITH UTILITY LOCATING DEVICES AND SYSTEMS; U.S. patent application Ser. No. 15/626, 399, filed Jun. 19, 2017, entitled SYSTEMS AND METHODS FOR UNIQUELY IDENTIFYING BURIED UTILITIES IN A MULTI-UTILITY ENVIRONMENT; U.S. Pat. No. 9,684,090, issued Jun. 20, 2017, entitled NULLED-SIGNAL LOCATING DEVICES, SYSTEMS, AND METHODS; U.S. Pat. No. 9,696,447, issued Jul. 4, 2017, entitled BURIED OBJECT METHODS AND APPARATUS USING MULTIPLE ELECTROMAGNETIC SIGNALS; U.S. Pat. No. 9,696,448, issued Jul. 4, 2017, entitled GROUND-TRACKING DEVICES FOR USE WITH A MAPPING LOCATOR; U.S. patent application Ser. No. 15/670,845, filed Aug. 7, 2017, entitled HIGH FREQUENCY AC-POWERED DRAIN CLEANING AND INSPECTION APPARATUS AND METHODS; U.S. patent application Ser. No. 15/681,250, Aug. 18, 2017, entitled ELECTRONIC MARKER DEVICES AND SYSTEMS; U.S. patent application Ser. No. 15/681,409, filed Aug. 20, 2017, entitled WIRELESS BURIED PIPE AND CABLE LOCATING SYSTEMS; U.S. Pat. No. 9,746,572, issued Aug. 29, 2017, entitled ELECTRONIC MARKER DEVICES AND SYSTEMS; U.S. Pat. No. 9,746,573, issued Aug. 29, 2017, entitled WIRELESS BURIED PIPE AND CABLE LOCATING SYSTEMS; U.S. patent application Ser. No. 15/701,247, now U.S. Pat. No. 10,171,721, issued Sep. 11, 2017, entitled PIPE INSPECTION SYSTEMS WITH SELF-GROUNDING PORTABLE CAMERA CONTROLLER; U.S. Pat. No. 9,769,366, issued Sep. 19, 2017, entitled SELF-GROUNDING TRANSMITTING PORTABLE CAMERA CONTROLLER FOR USE WITH PIPE INSPECTION SYSTEMS; U.S. patent application Ser. No. 15/728,250, now U.S. Pat. No. 10,324,188, filed Oct. 9, 2017, entitled OPTICAL GROUND TRACKING APPARATUS, SYSTEMS, AND METHODS FOR USE WITH BURIED UTILITY LOCATORS; U.S. patent application Ser. No. 15/728,410, now U.S. Pat. No. 10,359,368, filed Oct. 9, 2017, entitled PIPE INSPECTION SYSTEM WITH JETTER PUSH-CABLE; U.S. Pat. No. 9,784,837, issued Oct. 10, 2017, entitled OPTICAL GROUND TRACKING APPARATUS, SYSTEMS, AND METHODS; U.S. patent application Ser. No. 15/785,330, filed Oct. 16, 2017, entitled SYSTEMS AND METHODS OF USING A SONDE DEVICE WITH A SECTIONAL FERRITE CORE STRUCTURE; U.S. Pat. No. 9,791,382, issued Oct. 17, 2017, entitled PIPE INSPECTION SYSTEM WITH JETTER PUSH-CABLE; U.S. Pat. No. 9,798,033, issued Oct. 24, 2017, entitled SONDE DEVICES INCLUDING A SECTIONAL FERRITE CORE; U.S. patent application Ser. No. 15/805,007, filed Nov. 6, 2017, entitled PIPE INSPECTION SYSTEM CAMERA HEADS; U.S. patent application Ser. No. 15/806,219, filed Nov. 7, 2017, entitled MULTI-CAMERA PIPE INSPECTION APPARATUS, SYSTEMS AND METHODS; U.S. Provisional Patent Application 62/580, 386 filed Nov. 1, 2017, now U.S. patent application Ser. No. 16/178,494 filed Nov. 1, 2018, entitled THREE AXIS MEASUREMENT MODULES AND SENSING METHODS; U.S. patent application Ser. No. 15/811,264, now U.S. Pat. No. 10,379,436, filed Nov. 13, 2017, entitled SPRING ASSEMBLIES WITH VARIABLE FLEXIBILITY FOR USE WITH PUSH-CABLES AND PIPE INSPECTION

SYSTEMS; U.S. patent application Ser. No. 15/811,361, filed Nov. 13, 2017, entitled OPTICAL GROUND TRACKING APPARATUS, SYSTEMS, AND METHODS; U.S. Pat. No. 9,824,433, issued Nov. 21, 2017, entitled PIPE INSPECTION SYSTEM CAMERA HEADS; U.S. Pat. No. 9,829,783, issued Nov. 28, 2017, entitled SPRING ASSEMBLIES WITH VARIABLE FLEXIBILITY FOR USE WITH PUSH-CABLES AND PIPE INSPECTION SYSTEMS; U.S. Pat. No. 9,835,564, issued Dec. 5, 2017, entitled MULTI-CAMERA PIPE INSPECTION APPARATUS, SYSTEMS, AND METHODS; U.S. Pat. No. 9,841,503, issued Dec. 12, 2017, entitled OPTICAL GROUND TRACKING APPARATUS, SYSTEMS, AND METHODS; U.S. patent application Ser. No. 15/846,102, filed Dec. 18, 2017, entitled SYSTEMS AND METHODS FOR ELECTRONICALLY MARKING, LOCATING, AND VIRTUALLY DISPLAYING BURIED UTILITIES; U.S. patent application Ser. No. 15/866,360, filed Jan. 9, 2018, entitled TRACKED DISTANCE MEASURING DEVICE, SYSTEMS, AND METHODS; U.S. patent application Ser. No. 15/870,787, filed Jan. 12, 2018, entitled MAGNETIC FIELD CANCELING AUDIO SPEAKERS FOR USE WITH BURIED UTILITY LOCATORS OR OTHER DEVICES; U.S. Provisional Patent Application 62/620,959 filed Jan. 23, 2018, now U.S. patent application Ser. No. 16/255,524 filed Jan. 23, 2019, entitled RECHARGEABLE BATTERY PACK ONBOARD CHARGE STATE INDICATION METHODS AND APPARATUS; U.S. Pat. No. 9,880, 309, issued Jan. 30, 2018, entitled UTILITY LOCATOR TRANSMITTER APPARATUS AND METHODS; U.S. patent application Ser. No. 15/889,067, filed Feb. 5, 2018, entitled UTILITY LOCATOR TRANSMITTER DEVICES, SYSTEMS, AND METHODS WITH DOCKABLE APPARATUS; U.S. Pat. No. 9,891,337, issued Feb. 13, 2018, entitled UTILITY LOCATOR TRANSMITTER DEVICES, SYSTEMS, AND METHODS WITH DOCKABLE APPARATUS; U.S. patent application Ser. No. 15/919,077, filed Mar. 12, 2018, entitled PORTABLE PIPE INSPECTION SYSTEMS AND METHODS; U.S. Pat. No. 9,914,157, issued Mar. 13, 2018, entitled METHODS AND APPARATUS FOR CLEARING OBSTRUCTIONS WITH A JETTER PUSH-CABLE APPARATUS; U.S. patent application Ser. No. 15/922,703, filed Mar. 15, 2018, entitled SELF-LEVELING INSPECTION SYSTEMS AND METHODS; U.S. patent application Ser. No. 15/925,643, filed Mar. 19, 2018, entitled PHASE-SYNCHRONIZED BURIED OBJECT TRANSMITTER AND LOCATOR METHODS AND APPARATUS; U.S. patent application Ser. No. 15/925,671, filed Mar. 19, 2018, entitled MULTI-FREQUENCY LOCATING SYSTEMS AND METHODS; U.S. Pat. No. 9,924,139, issued Mar. 20, 2018, entitled PORTABLE PIPE INSPECTION SYSTEMS AND APPARATUS; U.S. patent application Ser. No. 15/936,250, filed Mar. 26, 2018, entitled GROUND TRACKING APPARATUS, SYSTEMS, AND METHODS; U.S. Pat. No. 9,927,368, issued Mar. 27, 2018, entitled SELF-LEVELING INSPECTION SYSTEMS AND METHODS; U.S. Pat. No. 9,927, 545, issued Mar. 27,2018, entitled MULTI-FREQUENCY LOCATING SYSTEM AND METHODS; U.S. Pat. No. 9,928,613, issued Mar. 27, 2018, entitled GROUND TRACKING APPARATUS, SYSTEMS, AND METHODS; U.S. Provisional Patent Application 62/656,259 filed Apr. 11, 2018, now U.S. patent application Ser. No. 16/382,136 filed Apr. 11, 2019, entitled GEOGRAPHIC MAP UPDATING METHODS AND SYSTEMS; U.S. patent application Ser. No. 15/954,486, filed Apr. 16, 2018, entitled UTILITY LOCATOR APPARATUS, SYSTEMS, AND METHODS; U.S. Pat. No. 9,945,976, issued Apr. 17, 2018, entitled UTILITY LOCATOR APPARATUS, SYSTEMS, AND METHODS; U.S. patent application Ser. No. 15/960,340, filed Apr. 23, 2018, entitled METHODS AND SYSTEMS FOR GENERATING INTERACTIVE MAPPING DISPLAYS IN CONJUNCTION WITH USER INTERFACE DEVICES; U.S. Pat. No. 9,959,641, issued May 1, 2018, entitled METHODS AND SYSTEMS FOR SEAMLESS TRANSITIONING IN INTERACTIVE MAPPING SYSTEMS; U.S. Provisional Patent Application 62/686,589 filed Jun. 18, 2018, now U.S. patent application Ser. No. 16/443, 789 filed Jun. 17, 2019, entitled MULTI-DIELECTRIC COAXIAL PUSH-CABLES; U.S. Provisional Patent Application 62/688,259 filed Jun. 21, 2018, now U.S. patent application Ser. No. 16/449,187 filed Jun. 21, 2019, entitled ACTIVE MARKER DEVICES FOR UNDERGROUND USE; U.S. Provisional Patent Application 62/726,500 filed Sep. 4, 2018, now U.S. patent application Ser. No. 16/559, 576 filed Sep. 3, 2019, entitled VIDEO PIPE INSPECTION SYSTEMS, DEVICES, AND METHODS INTEGRATED WITH NON-VIDEO DATA RECORDING AND COMMUNICATION FUNCTIONALITY; U.S. Provisional Patent Application 62/897,141, filed Sep. 6, 2019, entitled INTEGRATED FLEX-SHAFT CAMERA SYSTEM WITH HAND CONTROL; U.S. patent application Ser. No. 16/144, 878, filed Sep. 27, 2018, entitled MULTIFUNCTION BURIED UTILITY LOCATING CLIPS; U.S. Provisional Patent Application 62/759,955, filed Nov. 12, 2018, entitled HEAT EXTRACTION ARCHITECTURE FOR COMPACT VIDEO CAMERA HEADS; and U.S. Provisional Patent Application 62/794,863, filed Jan. 21, 2019, entitled HEAT EXTRACTION ARCHITECTURE FOR COMPACT VIDEO CAMERA HEADS. The content of each of the above-described patents and applications is incorporated by reference herein in its entirety. The above-described patent applications and patents may be referred to herein collectively as the "incorporated applications."

As used herein, the term "in-pipe" may refer to anything detectable at or near the location of the camera head generally during the operation of a pipe inspection.

The term "non-video" as used in "non-video data" or "non-video related sensors" may generally relate to aspects of the camera head or inspection not relating to the image sensor(s) or video generated therefrom. Such aspects may generally refer to sensors or data generated in the camera head not directly relating to the video.

The term "computing devices" may refer to any device for displaying the video and/or non-video data that may be generated as well as accepting user input to generate commands that may be communicated to the camera head and/or other devices (e.g., electronic devices) in the pipe inspection system. "User input" may refer to input explicitly input by the user or implicitly input such as a biometric scan. "User input" may further refer to input from any of the various system sensors. Exemplary display and user input elements may include, but should not be limited to, smart phones, tablets, laptop computers, or other electronic computing devices that may be connected via a wired or wireless connection.

The term "access point" may refer to the entrance location of a camera head into a pipe or other inspection cavity. Such access points may generally exist at or near the ground surface but may also appear at other entrance locations in the pipe or other conduit.

The following exemplary embodiments are provided for the purpose of illustrating examples of various aspects, details, and functions of the present disclosure; however, the described embodiments are not intended to be in any way limiting. It will be apparent to one of ordinary skill in the art that various aspects may be implemented in other embodiments within the spirit and scope of the present disclosure. As used herein, the term, "exemplary" means "serving as an example, instance, or illustration." Any aspect, detail, function, implementation, and/or embodiment described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other aspects and/or embodiments.

Various additional aspects, features, devices, systems, and functionality are further described below in conjunction with the appended Drawings.

Example Pipe Inspection and/or Mapping Camera Heads, Systems, and Methods

FIG. **1**A illustrates a pipe inspection and mapping system embodiment **100** in accordance with aspects of the present disclosure. Inspection and mapping system **100** may include a motion tracking camera head **110** coupled to a push cable **120**, allowing the camera head **110** to be pushed into a pipe **125** and/or other conduit or void by a user **130** or via user-controlled or automated mechanical force. The push cable **120** may be a push-cable as described in, for example, the following co-assigned patents and patent applications: U.S. Pat. No. 5,457,288, issued Oct. 10, 1995, entitled Dual Push-Cable for Pipe Inspection; U.S. Pat. No. 5,808,239, issued Sep. 15, 1998, entitled Video Push-Cable; U.S. Pat. No. 5,939,679, issued Aug. 17, 1999, entitled Video Push-Cable; U.S. patent application Ser. No. 11/679,092, filed Feb. 26, 2007, entitled Light Weight Sewer Cable; U.S. patent application Ser. No. 13/589,948, now U.S. Pat. No. 8,984,698, filed Aug. 20, 2012, entitled Light Weight Sewer Cable; U.S. patent application Ser. No. 13/874,879, now U.S. Pat. No. 9,448,376, filed May 1, 2013, entitled High Bandwidth Push-Cables for Pipe Inspection Systems; and/or U.S. patent application Ser. No. 14/207,517, filed Mar. 12, 2014, entitled High Bandwidth Push-Cables for Pipe Inspection Systems. The content of each of these applications is incorporated by reference herein in its entirety. A push cable spring **135** may further couple between the push cable **120** and camera head **110**. The spring **135** may be used to further improve movement and/or handling of the camera head **110** into and inside the pipe **125** or other void. The push cable spring **135** may be of the variety described in, for example, co-assigned U.S. patent Ser. No. 14/271,255, now U.S. Pat. No. 9,477,147, filed May 6, 2014, entitled Spring Assemblies with Variable Flexibility for use with Push-Cables and Pipe Inspection Systems, the content of which is incorporated by reference herein in its entirety.

A cable storage drum or drum reel **140** or other apparatus for dispensing push cable **120** may further be coupled to a proximal end of the push cable **120**. The camera head **110** may be coupled to a distal end of the push cable **120**. The drum reel **140** may be a reel/cable storage drum as described, for example, in co-assigned patents and patent applications including: U.S. Pat. No. 6,958,767, issued Oct. 25, 2005, entitled Video Pipe Inspection System Employing Non-Rotating Cable Storage Drum; U.S. patent application Ser. No. 12/704,808, now U.S. Pat. No. 10,009,582, filed Feb. 12, 2010, entitled Pipe Inspection System with Replaceable Cable Storage Drum; U.S. patent application Ser. No. 13/826,112, filed Mar. 14, 2013, entitled Systems and Methods Involving a Smart Cable Storage Drum and Network Node for Transmission of Data; U.S. patent application Ser. No. 14/216,358, filed Mar. 17, 2014, entitled Systems and Methods Involving a Smart Cable Storage Drum and Network Node and Methods; and/or U.S. patent application Ser. No. 14/469,536, now U.S. Pat. No. 9,521,303, filed Aug. 26, 2014, entitled Cable Storage Drum with Moveable CCU Docking Apparatus. The content of each of these applications is incorporated by reference herein in its entirety.

The drum reel **140** and/or other system device may further include a cable counting element (cable counting element **242** of FIG. **2**B) for generating cable counting data corresponding to the measured amount of push cable dispensed such as those described in, for example, co-assigned U.S. patent application Ser. No. 14/203,485, filed Mar. 10, 2014, entitled Pipe Inspection Cable Counter and Overlay Management System, and/or U.S. patent application Ser. No. 12/766,742, now U.S. Pat. No. 8,970,211, filed Apr. 23, 2010, entitled Pipe Inspection Cable Counter and Overlay Management System. The content of each of these applications is incorporated by reference herein in its entirety.

The system **100** may further include a processing element **145** for receiving at least inertial data generated at camera head **110** and cable counting data and generating control signals and output data from methods associated with corrected inertial data and pipe mapping. Storage **150** may include non-transitory computer-readable memory for storing video and non-video data as well as inertial data and associated output data generated by the processing element.

The system **100** may further include a display element **155** for displaying real time, near real time, and/or post processed video or still images and other system and camera head data.

The processing element **145** and associated storage **150** as well as display element **155** may be disposed in one or more system devices. For instance, processing, storage, and display of the pipe inspection and mapping and associated data may occur partially or fully in the camera head **110** or drum reel **140**. In some embodiments, various other devices such as electronic devices including a camera control unit (CCU) (such as the CCU **245** of FIGS. **2**A and **2**B), utility locating devices (such as the utility locating device **260** of FIGS. **2**A and **2**B), or other electronic or computing devices (such as laptop, smart phone, remote server, tablet or like computing device **250** of FIGS. **2**A and **2**B) may share or fully contain and perform the operations of the processing element **145**, storage **150**, and/or display element **155**.

Turning to FIG. **1**B, a diagram of the camera head **110** is illustrated. The camera head **110** may include one or image sensors **111** generating video signal(s) **112** which may be video and images of scenes from the inside of pipe **125** (FIG. **1**A) and one or more multi-axis inertial sensors such as one or more nine axis sensors **113** generating inertial data **114** relating to measured positions, orientations, and movements (or lack thereof) of camera head **110**. The one or more image sensors **111** may be high dynamic range (HDR) imagers or auto HDR imagers. The nine axis sensor **113** may include accelerometers, magnetometers, and gyroscopic sensors measuring inertial data in three dimensions. An illumination element **115** may be disposed in camera head **110** that may be or include LEDs or other light producing elements configured to illuminate the view of the one or more image sensors **111**.

The camera head **110** may include a processing element **116** configured to receive video signals **112** and inertial data **114** and, in some embodiments, other non-video data from other sensors or devices in other camera head or otherwise directly or indirectly wired or wirelessly coupled system devices. Such non-video data may include datalink signals **117** which may include instructions from other system devices. In some embodiments, the datalink signal **117** may include cable counting data from a cable counting element corresponding to the measured amount of push cable **120** (FIG. **1**A) dispensed from drum reel **140** (FIG. **1**A).

Corrected inertial data and pipe mapping methods, such as method **300** of FIG. **3**, may be performed partially or fully in the processing element **116** of camera head **110**. In other embodiments, such processing may occur in processing elements disposed in one or more other system devices (e.g., CCU **245** of FIG. **2**A, utility locating device **260** of FIG. **2**A, computing devices **250** of FIG. **2**A, or the like). The processing element **116** may be configured to receive such datalink signals **117** and perform operations relating to received instructions as well as communicate instructions to the various sensors and other elements of camera head **110**. Power **119** may likewise be provided to processing element **116** for provisioning to the camera head **110**. The processing element **116** may generate output video and non-video data signals **118** communicated via push cable **120** (FIG. **1**A) to other system devices. Output video and non-video data signals **118** may include data relating to video signal **112** and inertial data **114**.

Turning to FIG. **2**A, a pipe inspection and mapping system embodiment **200** in accordance with aspects of the present disclosure is disclosed which may include various other devices which may share or fully contain and perform the operations of the processing element **145** (FIG. **1**A), storage **150** (FIG. **1**), and/or display element **155** (FIG. **1**A).

Inspection and/or mapping system **200** may include a camera head **210** such as a motion tracking camera head, coupled to a push cable **220**, allowing the camera head **210** to be pushed into a pipe **225** and/or other conduit or void by a user **230** or via user-controlled or automated mechanical force. The push cable **220** may be a push cable as described in, for example, the following co-assigned patents and patent applications: U.S. Pat. No. 5,457,288, issued Oct. 10, 1995, entitled Dual Push-Cable for Pipe Inspection; U.S. Pat. No. 5,808,239, issued Sep. 15, 1998, entitled Video Push-Cable; U.S. Pat. No. 5,939,679, issued Aug. 17, 1999, entitled Video Push-Cable; U.S. patent application Ser. No. 11/679,092, filed Feb. 26, 2007, entitled Light Weight Sewer Cable; U.S. patent application Ser. No. 13/589,948, now U.S. Pat. No. 8,984,698, filed Aug. 20, 2012, entitled Light Weight Sewer Cable; U.S. patent application Ser. No. 13/874,879, now U.S. Pat. No. 9,448,376, filed May 1, 2013, entitled High Bandwidth Push-Cables for Pipe Inspection Systems; U.S. patent application Ser. No. 14/207,517, filed Mar. 12, 2014, entitled High Bandwidth Push-Cables for Pipe Inspection Systems; U.S. Pat. No. 10,356,360, issued Sep. 13, 2016, entitled High Bandwidth Push-Cables for Pipe Inspection Systems; and/or U.S. Provisional Patent Application 62/897,141, filed Sep. 6, 2019, entitled INTEGRATED FLEX-SHAFT CAMERA SYSTEM WITH HAND CONTROL. The content of each of these applications is incorporated by reference herein in its entirety.

A push cable spring **235** may further couple between the push cable **220** and camera head **210**. The spring **235** may be used to further improve movement and/or handling of the camera head **210** into and inside the pipe **225** or other void. The push cable spring **235** may be of the variety described in, for example, co-assigned U.S. patent application Ser. No. 14/271,255, now U.S. Pat. No. 9,477,147, filed May 6, 2014, entitled Spring Assemblies with Variable Flexibility for use with Push-Cables and Pipe Inspection Systems; U.S. Pat. No. 9,829,783, issued Oct. 17, 2016, entitled Spring Assemblies with Variable Flexibility for use with Push-Cables and Pipe Inspection Systems; and/or U.S. Pat. No. 10,379,436, issued Nov. 13, 2017, entitled Spring Assemblies with Variable Flexibility for use with Push-Cables and Pipe Inspection Systems, the content of which are incorporated by reference herein in its entirety. The various push cable springs described herein, such as push cable spring **235**, may be formed through a 3D printing process. In such embodiments, the 3D printing process may allow for low cost push cable springs having intricate details and thereby unique mechanical properties.

A drum reel **240** or other apparatus for dispensing push cable **220** may further be coupled to a proximal end of the push cable **220**. The camera head **210** may be coupled to a distal end of the push cable **220**. The drum reel **240** may be a reel/cable storage drum as described, for example, in co-assigned patents and patent applications including: U.S. Pat. No. 6,958,767, issued Oct. 25, 2005, entitled Video Pipe Inspection System Employing Non-Rotating Cable Storage Drum; U.S. patent application Ser. No. 12/704,808, now U.S. Pat. No. 10,009,582, filed Feb. 12, 2010, entitled Pipe Inspection System with Replaceable Cable Storage Drum; U.S. patent application Ser. No. 13/826,112, filed Mar. 14, 2013, entitled Systems and Methods Involving a Smart Cable Storage Drum and Network Node for Transmission of Data; U.S. patent application Ser. No. 14/216,358, filed Mar. 17, 2014, entitled Systems and Methods Involving a Smart Cable Storage Drum and Network Node and Methods; U.S. patent application Ser. No. 14/469,536, now U.S. Pat. No. 9,521,303, filed Aug. 26, 2014, entitled Cable Storage Drum with Moveable CCU Docking Apparatus; and/or U.S. Pat. No. 10,084,945, issued Dec. 5, 2016, entitled Cable Storage Drum with Moveable CCU Docking Apparatus. The content of each of these applications is incorporated by reference herein in its entirety.

The drum reel **240** and/or other system devices may further include a cable counting element (cable counting element **242** of FIG. **2**B) for generating cable counting data corresponding to the measured the amount of push cable dispensed (e.g., a cable or distance counter), such as those described in, for example, co-assigned U.S. patent application Ser. No. 14/203,485, filed Mar. 10, 2014, entitled Pipe Inspection Cable Counter and Overlay Management System, and/or U.S. patent application Ser. No. 12/766,742, now U.S. Pat. No. 8,970,211, filed Apr. 23, 2010, entitled Pipe Inspection Cable Counter and Overlay Management System. The content of each of these applications is incorporated by reference herein in its entirety.

The system **200** may further include a CCU **245** which may display images, video, and/or data provided from the camera head **210**. The CCU **245** may further control operation of the camera head **210**, displayed images/video, and/or other devices within the inspection system. Likewise, processing and storage of camera head data, including inertial data, may occur at the CCU **245**. The CCU **245** may, for example, be a device as described in co-assigned U.S. patent application Ser. No. 13/941,381, now U.S. Pat. No. 9,769,366, filed Jul. 12, 2013, entitled Self-Grounding Transmitting Portable Camera Controller for Use with Pipe Inspection Systems, and/or U.S. patent application Ser. No. 14/213,458, filed Mar. 14, 2014, entitled Self-Grounding Transmitting Portable Camera Controller for Use with Pipe Inspection Systems. The content of each of these applications is incorporated by reference herein in its entirety. The displaying, processing, and storage of video data and other camera head data, including inertial data, may occur in one or more other computing devices **250**. Such computing devices may include laptops, smart phones, remote servers, tablets or the like.

The system **200** may include a Sonde device **255** at a known location along push cable **220** from camera head **210** and/or, in some embodiments, disposed inside camera head **210**. The Sonde device **255** may generate a dipole electromagnetic field from within pipe **225**, which may then be detected by a buried utility locating device, such as utility locating device **260**, to determine the position of the Sonde device **255** (below the ground) at the ground surface. The Sonde device **255** may, for example, be a Sonde such as those described in co-assigned patents and patent applications including: U.S. Pat. No. 7,221,136, issued May 22, 2007, entitled Sondes for Locating Underground Pipes and Conduits; U.S. Pat. No. 7,298,126, issued Nov. 20, 2007, entitled Sondes for Locating Underground Pipes and Conduits; U.S. Pat. No. 7,863,885, issued Jan. 4, 2011, entitled Sondes for Locating Underground Pipes and Conduits; U.S. patent application Ser. No. 14/027,027, filed Sep. 13, 2013, entitled Sonde Devices Including a Sectional Ferrite Core Structure; and/or U.S. patent application Ser. No. 14/215,290, now U.S. Pat. No. 9,798,033, filed Mar. 17, 2014, entitled Sonde Devices Including a Sectional Ferrite Core Structure. The content of each of these applications is incorporated by reference herein in its entirety. In some embodiments, the one or more Sonde devices **255** may be multi-frequency devices configured to broadcast at a multitude of frequencies. In some embodiments, a unique frequency may be broadcast by the Sonde **255** measurable by a utility locator device **260** to determine locate points at the ground surface. Such locate points may be used to correlate a pipe map to the ground surface, determine or correct directions of the camera head, and/or identify location of aspects inside the pipe.

The utility locating device **260** of system **200** may be used to determine and/or map the location of pipes buried within the ground including pipe locations correlating with video or still images and associated pipe data generated at the camera head **210**. In some such system embodiments, a utility locating device such as the utility locating device **260** may further be configured to receive image or video data and/or other data or information generated at the camera head, such as via a wireless data connection, and display and/or store images/video from the pipe inspection as transmitted via wireless data connection between the utility locating device **260** and CCU **245** or utility locating device **260** and drum reel **240**. In some system embodiments, such data may be communicated via a wired connection indirectly coupling the camera head **210** and the utility locating device **260**.

The utility locating device **260** may include a processing element for processing data, including inertial data from camera head **210**, and/or images or video from the camera head **210**. The locate data could be combined using synchronization from a common time base. Such a common time base may be achieved through GPS or synchronization of clocks by other means such as optical, audio, or electromagnetic synchronization pulses between system devices. The wireless communication/transceiver module may be, for example, a Bluetooth or Wi-Fi communication module, a cellular data communication module, or other wireless communication modules. In some embodiments, the utility locating device **260** may further be configured to control operational parameters of the camera head **210** and/or other system devices such as the CCU **245** and drum reel **240**.

Details of example utility locating devices as may be used in combination with the disclosures herein in various system embodiments are described in co-assigned patents and patent applications including: U.S. Pat. No. 7,009,399, issued Mar. 7, 2006, entitled Omnidirectional Sonde and Line Locator; U.S. Pat. No. 7,276,910, issued Oct. 2, 2007, entitled A Compact Self-Tuned Electrical Resonator for Buried Object Locator Applications; U.S. Pat. No. 7,288,929, issued Oct. 30, 2007, entitled Inductive Clamp for Applying Signal to Buried Utilities; U.S. Pat. No. 7,443,154, issued Oct. 28, 2008, entitled Multi-Sensor Mapping Omnidirectional Sonde and Line Locator; U.S. Pat. No. 7,518,374, issued Apr. 14, 2009, entitled Reconfigurable Portable Locator Employing Multiple Sensor Array Having Flexible Nested Orthogonal Antennas; U.S. Pat. No. 7,619,516, issued Nov. 17, 2009, entitled Single and Multi-Trace Omnidirectional Sonde and Line Locators and Transmitters Used Therewith; U.S. Pat. No. 7,825,647, issued Nov. 2, 2010, entitled Compact Line Illuminator for Locating Buried Pipes and Cables; U.S. Pat. No. 7,990,151, issued Aug. 2, 2011, entitled Tri-Pod Buried Locator System; U.S. patent application Ser. No. 13/469,024, now U.S. Pat. No. 9,207,350, filed May 10, 2012, entitled Buried Object Locator Apparatus and Systems; U.S. patent application Ser. No. 13/570,211, now U.S. Pat. No. 9,435,907, filed Aug. 8, 2012, entitled Phase-Synchronized Buried Object Locator Apparatus, Systems, and Methods; U.S. Pat. No. 8,248,056, issued Aug. 21, 2012, entitled A Buried Object Locator System Employing Automated Virtual Depth Event Detection and Signaling; U.S. Pat. No. 8,264,226, issued Sep. 11, 2012, entitled System and Method for Locating Buried Pipes and Cables with a Man Portable Locator and a Transmitter in a Mesh Network; U.S. patent application Ser. No. 13/676,989, now U.S. Pat. No. 9,638,824, filed Nov. 11, 2012, entitled Quad-Gradient Coils for Use in a Locating System; U.S. patent application Ser. No. 13/851,951, filed Mar. 27, 2013, entitled Dual Antenna Systems with Variable Polarization; U.S. patent application Ser. No. 14/214,151, filed Mar. 14, 2014, entitled Dual Antenna Systems with Variable Polarization; and/or U.S. patent application Ser. No. 14/446,279, now U.S. Pat. No. 9,632,199, filed Jul. 29, 2014, entitled Inductive Clamp Devices, Systems, and Methods. The content of each of these applications is incorporated by reference herein in its entirety.

As disclosed in the various above-listed incorporated patents and patent applications, a utility locating device may include one or more location or position sensors such as global position system (GPS) sensors, inertial sensors, magnetic sensors and the like. Such sensors may be used to track and interpret motion vectors as the utility locating device is moved about its operating surface and/or associate these with absolute position data such as latitude/longitude data or relative position data such as data relating the position of the locator to reference surface features or objects. This data may be combined with images and/or video to generate combined position and mapping data, which may be associated, stored in a memory, transmitted to other electronic computing devices and systems and the like. As described subsequently herein, such mapping solution data may include data corresponding to location imagery as well as data collected through a pipe inspection by a camera head to reference a ground surface location via a utility locator device and/or other system tool. Pipe inspection imagery and data may be displayed upon the utility locating device display, stored in a memory, and/or transmitted to other devices and systems for archiving, mapping, analysis, and the like.

The mapping and/or inspection system **200** of FIGS. **2**A and **2**B may further include an in-pipe accessory device **265** that may be configured to communicate with the camera head **210**. For instance, modulation of light emitted by the camera head **210** and/or in-pipe accessory device **265** may be used to transmit a modulated light signal whereas image or photo sensors in the camera head **210** and/or in-pipe accessory device **265** may be used to receive the modulated light signal. Each device, camera head **210** and in-pipe accessory device **265**, may include a processing element configured to receive transmitted modulated light signals and carry out operations relating to the commands or other communications. For instance, in FIG. **2**A, the in-pipe accessory device **265** is a grasping device for grasping objects that may be lost or otherwise disposed inside the pipe **225**. The modulated light signal from the camera head **210** may instruct the in-pipe accessory device **265** to grab onto an object. In some uses, the modulated light signals may include other commands, status of batteries or other device conditions, and/or other instructions between the devices. In other embodiments, other in-pipe accessory devices **265** may include, but are not limited to, pipe clearing devices, additional Sonde devices, crawling devices to aid in navigating pipes, or the like.

System **200** may include a tracked rangefinder device **270** configured to generate imagery of geolocations on the Earth's surface having coordinates in a world coordinate system. The tracked rangefinder device **270** may identify ground surface points that may be significant to the pipe inspection and mapping operations and/or locating. For instance, the tracked rangefinder device **270** may be used to identify the access point of the camera head **210** into pipe **225**. The tracked rangefinder device **270** may be or share aspects with the tracked distance finders and rangefinder devices such as those described in co-assigned application U.S. patent application Ser. No. 15/866,360, filed Jan. 9, 2018, entitled Tracked Distance Measuring Devices, Systems, and Methods and/or U.S. patent application Ser. No. 16/241,864, filed Jan. 7, 2019, entitled Tracked Distance Measuring Devices, Systems, and Methods, the content of which is incorporated by reference herein in its entirety.

System **200** may include a GPS backpack device **275** configured to determine or refine the geolocation of various systems in a world coordinate system. The GPS backpack device **275** may be of the variety described in the incorporated U.S. patent application Ser. No. 13/851,951, filed Mar. 31, 2012, entitled DUAL ANTENNA SYSTEMS WITH VARIABLE POLARIZATION; U.S. patent application Ser. No. 14/214,151, filed Mar. 29, 2013, entitled DUAL ANTENNA SYSTEMS WITH VARIABLE POLARIZATION; and U.S. patent application Ser. No. 16/525,157, filed Jul. 29, 2019, entitled DUAL ANTENNA SYSTEMS WITH VARIABLE POLARIZATION. The content of each of these applications is incorporated by reference herein in its entirety.

Turning to FIG. **2**B, a diagram of the pipe inspection and mapping system embodiment **200** is illustrated. The camera head **210** of system **200** may include one or image sensors **211** generating video signal(s) **212** which may be video and images of scenes from the inside of pipe **225** and one or more nine axis sensors **213** generating inertial data **214** relating to measured positions, orientations, and movements (or lack thereof) of the camera head **210**. The one or more image sensors **211** may be HDR or auto HDR imagers. The nine axis sensor **213** may include accelerometers, magnetometers, and gyroscopic sensors measuring inertial data related to movements of the camera head, generally in three dimensions. In some embodiments, the nine-axis sensors may instead be or include other inertial sensors and/or other sensors for or relating to measuring positions, orientations, and movements (or lack thereof) of a camera head which may occur along nine axes, six axes, or along any number axes or combination of sensors measuring along different axes. An illumination element **215** may be disposed in camera head **210** that may be or include LEDs or other light producing elements configured to illuminate the field of view of the one or more image sensors **211**.

The camera head **210** may include a processing element **216** configured to receive video signals **212** and inertial data **214** and, in some embodiments, other non-video data from other sensors or elements in the camera head or otherwise directly or indirectly wired or wirelessly coupled system devices. Such non-video data may include datalink signals **217** which may include instructions from other system devices. In some embodiments, the datalink signal **217** may include cable counting data from a cable counting element **242** corresponding to the measured amount of push cable **220** dispensed from drum reel **240**. The cable counting element **242** is illustrated as coupled to the drum reel **240** in system **200**. In some system embodiments, a cable counting element such as cable counting element **242** may be included for measuring the amount of push cable dispensed. Power **219** may likewise be provided to processing element **216** for provisioning to the camera head **210**. For instance, the CCU **245**, drum reel **240**, or other connected system device may be battery powered or otherwise connect to a power outlet which may further power the camera head **210**.

Corrected inertial data and pipe mapping methods, such as method **300** of FIG. **3**, may be performed partially or fully in the processing element **216** of camera head **210**. Likewise, such processing may occur in processing elements disposed in the CCU **245** and/or utility locating device **260** and/or computing devices **250** of FIGS. **2**A and **2**B and/or other system devices containing a processing element. Likewise, storage of system data, including video signals and data, inertial data, output of inertial data and pipe mapping methods, and/or other system data may occur in the CCU **245** and/or utility locating device **260** and/or computing devices **250** of FIGS. **2**A and **2**B and/or other system devices containing storage which may be transitory or non-transitory memory. The processing element **216** may be configured to receive datalink signals **217** and perform operations relating to received instructions as well as communicate instructions to the various sensors and other elements of camera head **210**.

The processing element **216** may generate output video and non-video data signals **218** communicated via push cable **220** to the CCU **245** and/or utility locating device **260** and/or computing devices **250** of FIGS. **2**A and **2**B and/or other system devices. Output video and non-video data signals **218** may include data relating to video signal **212** and inertial data **214**.

Displaying of video/image data may occur at one or more system devices equipped with a display element (e.g., CCU **245**, utility locating device **260**, computing devices **250**, or the like). A wireless link **280** may allow the exchange of data between the drum reel **240** and/or CCU **245** and the utility locating device **260** as well as the exchange of data between the drum reel **240** and/or CCU **245** and one or more other wirelessly connected computing devices **250**. The computing devices **250** may be or include smart phones, laptop computers, and/or other like portable or non-portable computing devices **250**. In some embodiments, such computing devices **250** may include one or more remote servers.

Turning to FIG. **3**, a method **300** for generating corrected inertial data and a subsequent pipe map is described. In a step **310**, the pipe inspection operation may begin. In a step **320**, the location of the access point of the camera head into a pipe is determined. The step **320** may be accomplished in various ways. For instance, in some method embodiments, the access point location may be input by a user using a GPS device or by identifying the access point on a map. In some method embodiments, the access point location may be identified by a tracked rangefinder device such as the tracked range finder device **270** of FIG. **2**A. In yet further embodiments, the camera head may be configured to identify the access point upon entry and determine the location of the access point in a world coordinate system.

In a step **330**, the direction of the camera head may be determined. Step **330** may include the use of magnetometers in the camera head. In some embodiments, the magnetometer data may be corrected or enhanced by location points on the ground surface (e.g., such as the location points described in conjunction with operation **400** of FIG. **4**). In some embodiments, the ground surface location points alone may be used to determine camera head direction. In parallel steps **340**, **342**, and **344**, the camera head may be moved forward (in a forward direction or first direction) through the pipe while simultaneously determining push cable count data representing the length of push cable dispensed from the drum reel and outgoing inertial navigation data generated at the camera head. In parallel steps **350**, **352**, and **354**, the camera head may be moved in the reverse direction (or second direction) through the pipe while simultaneously determining push cable count data representing the length of push cable dispensed back into the drum reel and ingoing inertial navigation data generated at the camera head.

In a following step **360**, outgoing and ingoing inertial data may be correlated based on push cable count data. In a step **370**, corrected inertial data may be generated based on correlating ingoing and outgoing inertial data. For instance, the step **370** may include a metric whereby if ingoing and outgoing inertial data agrees to within a threshold, an averaging of inertial data may be determined as correct for the correlated cable count data location. In correlated cable count data locations wherein the ingoing and outgoing inertial data falls outside of a threshold, the inertial data may be discarded. In some embodiments, the correlated cable count data locations may further correlate to in-pipe images or video. The in-pipe images or video may be accessed to determine whether the inertial data is in agreement with what is occurring in the pipe. For instance, inertial data corresponding to a corner or turn may be identified in the video and thereby verified as correct.

In a subsequent step **380**, a pipe map may be generated based on the corrected inertial data. For instance, such a pipe map may use 3D reconstruction techniques to reconstruct the bends and turns inside of the inspected pipe. Video or other pipe inspection imagery, as well as other inspection data, may further correlate to the correlated cable count data locations of the pipe map. In a step **390**, the pipe map location may be correlated to ground surface locations based on access point location of step **320** and camera head direction of step **330**.

Turning to FIG. **4**, a pipe inspection and mapping operation **400** is illustrated. In operation **400**, various locate points (also referred to as location points) (**410***a*, **410***b*, and **410***c*) may be ground level locations corresponding to pipe **420** locations. For instance, as a camera head is moved through the pipe **420**, a Sonde device disposed in the camera head and/or on the push cable at a known distance from the camera head may broadcast a signal measurable by a utility locating device **440** carried by a user **450**. The Sonde broadcast locations, **460***a*, **460***b*, and **460***c*, may be determined at the utility locating device **440** to correspond to ground level locate points **410***a*, **410***b*, and **410***c*. In such embodiments, a pipe map may be fitted to a map of the ground surface. In some embodiments, the geolocation of the access point **425** of the pipe **420** may be determined, and locate points, such as locate points **410***a*, **410***b*, and **410***c*, may be used to determine the direction of the camera head or correct direction of the camera head.

Still referring to FIG. **4**, the Sonde devices may be configured to always be on during an inspection and separate from the camera head. In system embodiments wherein the camera head includes one or more compass or other inertial sensors, such as the camera head **110** of FIG. **1**B or camera head **210** of FIG. **2**B or camera head **510** of FIG. **5** or camera head **610** of FIG. **6**, the Sonde device(s) may be modulated to avoid saturating the input of such sensors. In some embodiments, the modulation of the Sonde device may be controlled by a motion metric determined by inertial sensors and/or the cable counting element and/or motion detected visually through the image sensor(s). For instance, the signal level of the Sonde device may be increased when the camera head is stationary or near stationary and decreased when in motion. In some embodiments, the change in received Sonde device signal at the compass sensor may be used to determine the position of the Sonde device relative to the camera head. This known position of the Sonde device relative to the camera head may be further be used to determine past position of the camera head. A succession of past camera head positions may further determine a path traveled by a camera head which may further be mapped and stored.

Turning to FIG. **5**, a diagram of a camera head **510** in keeping with the present disclosure is illustrated which may be a self-leveling camera head having both stationary and rotating assemblies. The stationary assembly may refer to the internal camera component assembly or assemblies that are moveable relative to the camera head housing. The rotating assembly may refer to the internal camera assembly or assemblies configured to rotate relative to the camera head housing. Such rotations may generally allow the rotating assembly components to remain upright with respect to gravity.

The camera head **510** may be or share aspects with the mechanical or digital self-leveling camera heads described in U.S. patent application Ser. No. 13/358,463, now U.S. Pat. No. 9,927,368, filed Jan. 25, 2012, entitled Self-Leveling Inspection Systems and Methods and U.S. Pat. No. 8,587,648, issued Nov. 19, 2013, entitled Self-Leveling Camera Head. The content of each of these applications is incorporated by reference herein in its entirety.

The image sensors of camera head **510** may be one or more Auto HDR image sensors **511** generating HDR video signal(s) **512** which may be video and images of scenes from the inside of a pipe. The image sensor(s) **511** may be disposed in the rotating assembly of camera head **510** such that the image sensor(s) rotate to be upright with respect to gravity. The camera head **510** may also include one or more multi-axis sensors, such as one or more nine axis sensors **513** in the rotating assembly for generating inertial data **514** relating to measured positions, orientations, and movements (or lack thereof) of camera head **510**. The nine axis sensors **513** may include accelerometers, magnetometers, and gyroscopic sensors measuring inertial data in three dimensions. The nine axis sensor **513** of FIG. **5** may further include an optional thermometer configured to measure temperature in the camera head **510**.

The rotating assembly of camera head **510** may further include a variety of other non-video sensors and elements. For instance, the rotating assembly of camera head **510** may include a multi-frequency Sonde **520**, a microphone **530**, and/or a variety of other sensors **540** (e.g., humidity sensors, rangefinder sensors, or the like). The multi-frequency Sonde **520** may broadcast a multitude of electromagnetic dipole signals that may be measured at the ground surface by a utility locating device. The microphone **530** and other sensors **540** may produce non-video data **550** relating to in-pipe audio and other non-video aspects.

The stationary assembly may include an illumination element **515** which may be or include LEDs or other light producing elements configured to illuminate the view of the one or more image sensors **511**. One or more other sensors **540** (e.g., humidity sensors, rangefinder sensors, or the like) may also be included in the stationary assembly producing non-video data. In some embodiments, the stationary assembly may include one or more additional nine axis sensors configured to produce inertial data which may be compared against inertial data generated by nine axis sensors in the rotating assembly. In camera head **510**, a processing element **516** may be disposed on the stationary assembly configured to receive video signals **512**, inertial data **514**, and non-video data **550** such as that from microphone **530** and other sensors **540** and/or, in some embodiments, other non-video data from other devices in other camera head or otherwise directly or indirectly wired or wirelessly coupled system devices. Such non-video data may include datalink signals **517** which may include instructions from other system devices. In some embodiments, the datalink signal **517** may include cable counting data from a cable counting element corresponding to the measured amount of the push cable dispensed from a drum reel.

Corrected inertial data and pipe mapping methods, such as method **300** of FIG. **3**, may be performed partially or fully in the processing element **516** of camera head **510** and/or in the various processing elements of other system devices (e.g., CCU, utility locating device, other computing devices, or the like). The processing element **516** may be configured to receive datalink signals **517** and perform operations relating to received instructions as well as communicate instructions to the various sensors and other elements of camera head **510**. Power **519** may likewise be provided to processing element **516** for provisioning to the camera head **510**. The processing element **516** may generate output video and non-video data signals **518** communicated via the push cable to other system devices. Output video and non-video data signals may include data relating to video signals **512**, inertial data **514**, and other non-video data **550**.

Turning to FIG. **6**, a diagram of a camera head **610** in keeping with the present disclosure is illustrated which may be a self-leveling camera head having processing elements in both the rotating and stationary assemblies. The camera head **610** may be or share aspects with the mechanical or digital self-leveling camera heads described in U.S. patent application Ser. No. 13/358,463, now U.S. Pat. No. 9,927,368, filed Jan. 25, 2012, entitled Self-Leveling Inspection Systems and Methods, and U.S. Pat. No. 8,587,648, issued Nov. 19, 2013, entitled Self-Leveling Camera Head. The content of each of these applications is incorporated by reference herein in its entirety.

The image sensor(s) **611** of camera head **610** may be one or more HDR or auto HDR sensors generating video signal(s) **612** which may be video and images of scenes from the inside of a pipe. The image sensor(s) **611** may be disposed in the rotating assembly of camera head **610** such that the image sensor(s) rotate to be upright with respect to gravity. The camera head **610** may also include one or more nine axis sensors **613** in the rotating assembly for generating inertial data **614** relating to measured positions, orientations, and movements (or lack thereof) of camera head **610**. The nine axis sensor **613** may include accelerometers, magnetometers, and gyroscopic sensors measuring in three dimensions. The nine axis sensor **613** of FIG. **6** may further include an optional thermometer configured to measure temperature in the camera head **610**.

The rotating assembly of camera head **610** may further include a variety of other non-video sensors and elements. For instance, the rotating assembly of camera head **610** may include a microphone **630**, and/or a variety of other sensors **640** (e.g., humidity sensors, rangefinder sensors, or the like). A first processing element **660** may be included in the rotating assembly with image sensor(s) **611**. The first processing element **660** may be configured to control aspects relating to the operation of the image sensor(s) **611** and/or video signals **612** therefrom and or nine axis sensors **613**, associated inertial data **614**, and/or other sensors **640**. For instance, inertial data **614** from nine axis sensors **613** disposed in the stationary assembly of camera head **610** may be used to determine a motion metric that, when exceeding or falling within a certain threshold, may initiate the image sensor(s) to generate HDR imagery.

The stationary assembly may include an illumination element **615** which may be or include LEDs or other light producing elements configured to illuminate the view of the one or more image sensors **611**. One or more other sensors **640** (e.g., humidity sensors, rangefinder sensors, or the like) may also be included in the stationary assembly producing non-video data. In some embodiments, the stationary assembly may include one or more additional nine axis sensors configured to produce inertial data which may be compared against inertial data generated by the nine axis sensors in the rotating assembly.

The stationary assembly of camera head **610** may include one or more Sondes **620** which may broadcast electromagnetic signal(s) that may be measured at the ground surface by a utility locating device. A second processing element **670** may be disposed on the stationary assembly configured to receive video signals **612**, inertial data **614**, and non-video data **650** such as that from microphone **630** and other sensors **640** and/or, in some embodiments, other non-video data from other devices in other camera head or otherwise directly or indirectly wired or wirelessly coupled system devices. Such non-video data may include datalink signals **617** which may include instructions from other system devices. In some embodiments, the datalink signal **617** may include cable counting data from a cable counting element corresponding to the measured amount of the push cable dispensed from a drum reel.

Corrected inertial data and pipe mapping methods, such as method **300** of FIG. **3**, may be performed partially or fully in the processing element **670** of camera head **610** and/or in the various processing elements of other system devices (e.g., CCU, utility locating device, other computing devices, or the like). The processing element **670** may be configured to receive datalink signals **617** and perform operations relating to received instructions as well as communicate instructions to the various sensors and other elements of camera head **610**. Power **619** may likewise be provided to processing element **670** for provisioning to the camera head **610**. The processing element **670** may generate output video and non-video data signals **618** communicated via the push cable to other system devices. Output video and non-video data signals may include data relating to video signal **612**, inertial data **614**, and other non-video data **650**. The first processing element **660** of the rotating element and second processing element **670** of the stationary element may be configured to communicate data.

FIGS. **7**A-**7**C illustrate details of an exemplary embodiment of a self-leveling motion tracking camera head **710** configured to generate inertial data relating to measured positions, orientations, and movements (or lack thereof) as it is moved through a pipe, as well as to generate a video signal representing real time or near real time images of scenes from the inside of the pipe. The camera head **710** may include an outer housing assembly **720** having a front housing element **730** and rear housing element **740**. The front housing element **730** may have a window **732** allowing light to pass into the camera head **710** from the external environment. The window **732** may be glass, plastic, or sapphire ports that provide strength and protection against impacts, scratches, and other damage. The rear housing element **740** may have a connector **742** allowing the camera head **710** to attach to a push cable and provide power and communicate datalink as well as video and non-video data signals which may include inertial data generated therein. The front housing element **730** and rear housing element **740** may encapsulate a self-leveling camera module **750** (FIGS. **7**B and **7**C). A series of O-rings **760**-**766** (FIGS. **7**B and **7**C) may be disposed in camera head **710** to provide a water-tight seal protecting internal components from the ingress of water. In some embodiments, the housing assembly **720** may comprise non-magnetic materials.

Turning to FIGS. **8**A and **8**B, the self-leveling camera module **750** may have a stationary assembly **800** and a rotating assembly **850**. The stationary assembly **800** may be moveable relative to the housing assembly **720** (FIG. **7**A). The rotating assembly **850** may rotate relative to the housing assembly **720** (FIG. **7**A) allowing the rotating assembly components to remain upright with respect to gravity. The stationary assembly **800** may include a cylindrical hollow body element **810** with a cap assembly **820** coupled onto the back end of the body element **810** and an illumination element **830** coupled onto the forward end of the body element **810**.

A connector **840** may further connect the cap assembly **820** and illumination element **830** for purposes of signal/data communication as well as provisioning of power. The cap assembly **820** may include a cap body **822** dimensioned to fit onto the end of the cylindrical body element **810**. A PCB **824** may secure to the back of the cap body **822** which may contain the stationary assembly processing element. Pins **826** coupled to PCB **824** may further contact corresponding contact elements in the connector **742** (FIG. **7**C) and provide an electrical pathway further to a contact ring module **828** disposed on the inner side of the cap assembly **820**. The contact ring module **828** may have a series of stacked isolated electrical contacts that may, in assembly, protrude into the rotating assembly **850** and make contact with brush elements disposed in a brush contact module **950** (FIGS. **9**A and **9**B) to communicate signals/data as well as provide power to the rotating assembly **850**.

A bearing module **860** may fit about a lens module **910** (FIGS. **9**A and **9**B) of the rotating assembly **850** so as to be situated between the rotating assembly **850** and illumination element **830**. An additional bearing module **870** may seat between the back of the rotating assembly **850** and the cap assembly **820** of the stationary assembly **800**. The bearing modules **860** and **870** may allow the rotating assembly **850** to rotate about axis **880**. The bearing modules **860** and **870** may be of non-magnetic materials so as to not impact inertial data, Sondes optionally disposed in the camera head, or the like. In some embodiments, a rotary encoder may be disposed between the stationary assembly and a rotating assembly to measure rotations of the rotating assembly.

The illumination element **830** may include a series of LEDs **832** disposed on an annular PCB **834** dimensioned to allow the lens module **910** (FIGS. **9**A and **9**B) of the rotating assembly **850** to pass through. In some embodiments, the LEDs **832** may be controlled by a processing element (and/or from datalink or like control signals from other system devices) to allow control over how illuminated the field of view is and/or be modulated to generate a modulated light signal so as to communicate with an optional in-pipe accessory device. In some camera head embodiments, the PCB **834** may further include a number of other sensors or elements (e.g., humidity sensors, temperature sensors, rangefinder sensors, Sondes, nine axis sensors, or the like).

Turning to FIGS. **9**A and **9**B, the rotating assembly **850** may include a lens module **910**, a front counterweight housing **920**, an imaging and sensing module **930**, a series of screws **940**, a brush contact module **950**, a rear counterweight housing **960**, a light limiting element **970**, and a seal **980**. The imaging and sensing module **930** may include a PCB **932** with at least one imaging sensor **934**, which may be an HDR or auto HDR imaging sensor, and at least one nine axis sensor **936**. In some embodiments, the imaging and sensing module **930** may further include one or more other sensors or elements including, but not limited to humidity sensors, temperature sensors, rangefinder sensors, Sondes, and nine axis sensors.

In assembly, a light limiting element **970** may fit over the imaging sensor **934** and control the amount of light provided by the imaging sensor **934**. Seal **980** may seat between the imaging and sensing module **930** and brush contact module **950** providing a barrier for the brush contact module **950** in preventing the ingress of dust or debris and degrading the electrical contact made between the brush elements in the brush contact module **950** and contact rings of the of the contact ring module **828** (FIG. **8**A). Threads formed along the bottom of the lens module **910** may be made to mate with threads formed centrally about the top of the front counterweight housing **920** to secure the lens module **910** and the front counterweight piece **920** together. Screws **940** may secure imaging and sensing module **930** to the front counterweight housing **920** thus securing the light limiting element **970** in between. Desiccant paper may optionally be placed within the rear counterweight housing **960** and below the brush contact module **950** so as to aid in preventing corrosion and/or fogging of the lens.

The front counterweight housing **920** may be formed with a half-circle ridge formed along one edge which may provide additional mass along one side of the rotating assembly **850**. The rear counterweight housing **960** may be formed with a pocket along one side designed to fit a brush contact module **950** and provide an asymmetry in mass along the same side as the front counterweight housing **920**. The front counterweight housing **920** and the rear counterweight housing **960** may further comprise dense materials such as, but not limited to, steel, zinc, brass, tungsten, or filled plastics. In some embodiments, the housings **920** and **960** may be non-magnetic materials to not interfere with the inertial data generated by nine axis sensor(s) **934**. As the rotating assembly **850** may be made to rotate freely in respect to the stationary assembly **800** (FIGS. **8**A and **8**B), when in use, the asymmetry in mass along one side of the front counterweight housing **920** and the rear counterweight housing **960** may allow for the forces of gravity to operate as the leveling force of the camera head **710** (FIG. **7**A). The rear counterweight housing **960** may further secure to the bottom of the front counterweight housing **920** and have a hole **962** dimensioned to fit the contact rings of the contact ring module **828**.

In assembly, as illustrated in FIG. **10**, the contact rings of the contact ring module **828** may fit into the rear counterweight housing **960** and into the brush contact module **950**. Brushes in the brush contact module **950** may contact the contact rings of the contact ring module **828** providing electrical pathways for purposes of communicating signals and provisioning of power between the stationary assembly **800** and the rotating assembly **850**.

In some embodiments, the camera head may include one or more sensors configured as ranging devices to measure distances inside of a pipe or other inspection area. As illustrated in FIG. **11**, the camera head **1110** may be the camera head embodiment **110** of FIG. **1**, camera head **210** of FIGS. **2**A and **2**B, camera head **510** of FIG. **5**, camera head **610** of FIG. **6**, camera head **710** of FIGS. **7**A-**10** with the addition of rangefinder sensors and/or otherwise configured as a ranging device. Likewise, the camera head **1110** may be or share aspects with the camera head **1210** of FIG. **12**. The range finding may be achieved through one or more imaging sensors and/or through dedicated ranging devices/sensors such as vertical-cavity surface-emitting laser time of flight (VCSEL TOF) sensors. In some embodiments, one or more image sensors may operate for optical ranging. In some embodiments, a camera head such as camera head **1110** configured for generating ranging measurements may generate measurements of objects or elements in the pipe or other inspection area.

Turning to FIG. **12**, a diagram of a camera head **1210** in keeping with the present disclosure is illustrated which may be a self-leveling camera head configured for ranging. The stationary assembly may refer to the internal camera component assembly or assemblies that are moveable relative to the camera head housing. The rotating assembly may refer to the internal camera assembly or assemblies configured to rotate relative to the camera head housing. Such rotations may generally allow the rotating assembly components to remain upright with respect to gravity.

The camera head **1210** may be or share aspects with the mechanical or digital self-leveling camera heads described in U.S. patent application Ser. No. 13/358,463, filed Jan. 25, 2012, entitled Self-Leveling Inspection Systems and Methods and U.S. Pat. No. 8,587,648, issued Nov. 19, 2013, entitled Self-Leveling Camera Head. The content of each of these applications is incorporated by reference herein in its entirety.

The image sensors of camera head **1210** may be one or more Auto HDR image sensors **1211** generating HDR video signal(s) **1212** which may be video and images of scenes from the inside of a pipe. The image sensor(s) **1211** may be disposed in the rotating assembly of camera head **1210** such that the image sensor(s) rotate to be upright with respect to gravity. One or more of the image sensors **1211** may be configured as ranging sensors to measure distances and/or generate measurements of elements or objects in the pipe. Camera head **1210** may further include one or more dedicated ranging sensors **1245** likewise to measure distances and/or generate measurements of elements or objects in the pipe. The ranging sensors **1245** may be or include vertical-cavity surface-emitting laser time of flight (VCSEL TOF) sensors and/or other ranging sensors producing ranging data **1246** communicated with processing element **1216**.

Camera head **1210** may one or more inertial sensors and/or other camera head movement measuring sensor(s) **1213** for generating inertial data **1214** relating to measured positions, orientations, and movements (or lack thereof) of camera head **1210**. The inertial sensors and/or other camera head movement measuring sensor(s) **1213** may include accelerometers, magnetometers, gyroscopic sensors, and/or other sensors for or relating to measuring positions, orientations, and movements (or lack thereof) of camera head **1210**. The inertial sensor and/or other camera head movement measuring sensor(s) **1213** of FIG. **12** may further include an optional thermometer configured to measure temperature in the camera head **1210**. The inertial sensor(s) and/or other camera head movement measuring sensor(s) **1213** may be nine-axis sensors, six-axis sensors, or other sensors measuring along any number axes or combination of sensors measuring along different axes.

The rotating assembly of camera head **1210** may further include a variety of other non-video sensors and elements. For instance, the rotating assembly of camera head **1210** may include a multi-frequency Sonde **1220**, a microphone **1230**, and/or a variety of other sensors **1240** (e.g., humidity sensors, temperature sensors, or the like). The multi-frequency Sonde **1220** may broadcast a multitude of electromagnetic dipole signals that may be measured at the ground surface by a utility locating device. The microphone **1230** and other sensors **1240** may produce non-video data **1250** relating to in-pipe audio and other non-video aspects.

The stationary assembly may include an illumination element **1215** which may be or include LEDs or other light producing elements configured to illuminate the view of the one or more image sensors **1211**. One or more other sensors **1240** (e.g., humidity sensors, rangefinder sensors, or the like) may also be included in the stationary assembly producing non-video data. In some embodiments, the stationary assembly may include one or more additional nine axis sensors configured to produce inertial data which may be compared against inertial data generated by nine axis sensors and/or other camera head movement measuring sensors in the rotating assembly. In camera head **1210**, a processing element **1216** may be disposed on the stationary assembly configured to receive video signals **1212**, inertial data **1214**, ranging data **1246**, and non-video data **1250** such as that from microphone **1230** and other sensors **1240** and/or, in some embodiments, other non-video data from other devices in other camera head or otherwise directly or indirectly wired or wirelessly coupled system devices. Such non-video data may include datalink signals **1217** which may include instructions from other system devices. In some embodiments, the datalink signal **1217** may include cable counting data from a cable counting element corresponding to the measured amount of the push cable dispensed from a drum reel.

Corrected inertial data and pipe mapping methods, such as method **300** of FIG. **3**, may be performed partially or fully in the processing element **1216** of camera head **1210** and/or in the various processing elements of other system devices (e.g., CCU, utility locating device, other computing devices, or the like). The processing element **1216** may be configured to receive datalink signals **1217** and perform operations relating to received instructions as well as communicate instructions to the various sensors and other elements of camera head **1210**. Power **1219** may likewise be provided to processing element **1216** for provisioning to the camera head **1210**. The processing element **1216** may generate output video and non-video data signals **1218** communicated via the push cable to other system devices. Output video and non-video data signals may include data relating to video signals **1212**, inertial data **1214**, and other non-video data **1250**.

Some camera head and system embodiments in keeping with the present disclosure may be configured to perform depth from defocus measurements. As described in method **1300** of FIG. **13**, the pipe inspection system may be turned on in a step **1310**. For instance, a user may power on a system including at least a camera control unit that is coupled to a camera head. In a step **1320**, the camera head may be moved inside a pipe or other inspection area generating images of the inspection area. Such images may include still and/or video images. In a step **1330** parallel with step **1320**, a motion metric may be determined regarding the motion of the camera head. For instance, the motion metric may be determined by one or more multi-axis inertial sensors disposed in the camera head, cable counting element such as that disposed in the CCU, by detecting motion through image sensors in the camera head, and/or other motion sensing sensors or elements or a combination of the aforementioned sensors and elements. In a subsequent step **1340**, depth from defocus may be performed when the metric motion indicates the camera head is stationary or near stationary to within a predetermined threshold, the inspection system may perform depth from defocus measurements. The depth from defocus measurements may be processed in the camera head, CCU, other directly or wirelessly coupled system device or devices.

In some system embodiments, acoustic exciter devices may be employed at one or more locations to broadcast an audio signal which may be measured at the one or more microphones disposed in a camera head as disclosed herein. The spectral content of the audio signal measured at the camera head may allow the system to determine various aspects or qualities of the pipe or inspection environment.

As illustrated in FIG. **14**, the inspection system **1400** may include a camera head **1410** which may be or share aspects with camera heads disclosed herein that include at least one microphone such as the camera head **510** of FIG. **5** or camera head **610** of FIG. **6**. The camera head **1410** may be disposed on the distal end of a push cable **1420** that may be forced into a pipe **1425** or like inspection area by a user **1430** or other electromechanical auto-feeder device (not illustrated). The push cable **1420** may be dispensed from or into a drum reel **1440**. A CCU **1445** may be coupled to the drum reel **1440** to display images, video, and/or data provided from the camera head **1410**. The CCU **1445** may further control operation of the camera head **1410**, displayed images/video, and/or other devices within the inspection system. Likewise, processing and storage of camera head data may, in some embodiments, partially or fully occur in CCU **1445**. The system **1400** may further include a utility locating device **1460** as carried by user **1430**. One or more acoustic exciter devices **1465** may be present in various locations throughout the locate environment. As illustrated in FIG. **14**, some acoustic exciter device locations may include at the opening to the pipe **1425**, at ground level locations corresponding to the pipe location in the ground, carried with the user **1430**, and/or other locations oblique to the pipe in the ground. The acoustic exciters **1465** may broadcast an audio signal **1470** which may be measured at the one or more microphones disposed in the camera head **1410**. The spectral signature of the audio signal **1470** measured at the camera head **1410** may allow the system **1400** to determine various aspects or qualities of the pipe **1425** or inspection environment. For instance, the material and/or thickness of the material present in the pipe **1425** may alter spectral signature the audio signal **1470** measured at one or more microphones in the camera head **1410**. Each particular spectral signature may then be used to determine inspection or pipe parameters (e.g., pipe material type, pipe thickness, the structural integrity of the pipe, location of the camera head relative to the exciter as it traverses in the pipe or the like).

Turning to FIG. **15**, a method **1500** for using one or more acoustic exciter devices for pipe inspection systems is described. In a step **1510**, the pipe inspection system including one or more acoustic exciter devices are turned on. In a step **1520**, the camera head is moved in the pipe while measuring the acoustic signals broadcast by the one or more acoustic exciter devices. In a step **1530**, the spectral signal of the acoustic signals are compared against a database of spectral signals that correspond to various inspection or pipe parameters (e.g., pipe material type, pipe thickness, the structural integrity of the pipe, location of the camera head relative to the exciter as it traverses in the pipe, or the like). In a step **1540**, a best match to the database may be determined providing data regarding the related inspection and/or pipe parameters. The processing of acoustic signals may occur in the camera head, CCU, other connected or remotely coupled devices either in real time, near real time, or in post processing. In some embodiments, the acoustic data in combination with the inertial data collected by the camera head may be used to determine the material and/or size of the pipe. In some inspection systems having a camera head with one or more microphones, such as the camera head **510** of FIG. **5** or camera head **610** of FIG. **6**, may be configured to listen for and detect the proximity to nearby excavation to further generate alerts and/or actuate a kill switch turning off the excavation tools. Such a method is described with method **1600** of FIG. **16**. In a step **1610**, an inspection system including a camera head having one or more microphones may be turned on and the camera head may be moved into a pipe. In a step **1620**, the camera head may listen to audio signals generated by the excavation process. For instance, the excavation process may become louder as it approached the pipe or the audio signal may otherwise change as the excavating tools nears or contacts the pipe. In a step **1630**, access audio signal database and continually compare audio signals against those in the database to identify potential danger to the pipe. For instance, the audio signal database may include audio signals in an acceptable range (e.g., those sounds in a range determined as safe) or may include audio signals outside an acceptable range (e.g., those sounds in a range determined as unsafe wherein the utility may be damaged due to excavation) or may include audio signals that are in an acceptable range as well as those outside an acceptable range. In a step **1640**, upon identifying a danger to the pipe, the inspection system may generate alerts to alert user and/or excavation operators and/or actuate a kill switch to automate turning off of the excavation tools. In some such embodiments, the system may be equipped with a feeder device to retract the push cable and camera head.

Turning to FIGS. **17**A and **17**B, the camera head **1710**, which may be or share aspects with the various camera head embodiments disclosed herein further having a push cable spring **1720** couple behind camera head **1710** on the end. The push cable spring **1720**, as well as the various push cable springs described herein, may be formed through 3D printing process. In assembly, the opposite end of the push cable spring **1720** may couple to a push cable **1725** which, in an inspection system, further connect to a drum reel and a CCU such as the drum reel **1840** and CCU **1845** of system **1800** of FIG. **18**. In the assembly of FIGS. **17**A and **17**B, the push cable spring **1720** may be used to further improve movement and/or handling of the camera head **1710** into and inside a pipe or other void.

As illustrated in FIG. **17**B, a series of strain gauges **1730** may be arranged in various locations in the push cable spring **1720**. The strain gauges may transmit their output to the camera head **1710** and/or a CCU and/or other coupled or wirelessly connected system devices to estimate the configuration of the push cable spring **1720** as it moves through bends and turns in the pipe. In other embodiments, the one or more strain gauges may instead or additionally be disposed around or in a length of push cable, such as push cable **1725**, rather than in the push cable spring, such as push cable spring **1720**. In the various embodiments, the one or more strain gauges, such as strain gauges **1730**, may measure both the degree and direction of the movements. The strain gauge data may further be used to determine and map the path of the camera head through the pipe or other conduit.

A diagram of a pipe inspection and mapping system embodiment **1800** which may include one or more strain gauges (e.g., strain gauges **1856**) is illustrated in FIG. **18**. In system **1800**, a camera head **1810** may include one or image sensors **1811** generating video signal(s) **1812** which may be video and images of scenes from the inside of pipe **1825** and one or more inertial sensors and/or other camera head movement measuring sensor(s) **1813** generating inertial data **1814** relating to measured positions, orientations, and movements (or lack thereof) of the camera head **1810**. The inertial sensor(s) and/or other camera head movement measuring sensor(s) **1813** may include accelerometers, magnetometers, gyroscopic sensors, and/or other sensors for or relating to measuring positions, orientations, and movements (or lack thereof) of the camera head **1810**. The inertial sensor(s) and/or other camera head movement measuring sensor(s) **1813** may be nine-axis sensors, six-axis sensors, or other sensors measuring along any number axes or combination of sensors measuring along different axes. Such inertial data may further include movements estimating the configuration of a push cable **1820** coupled to camera head **1810** via one or more strain gauges **1856** as the assembly is moved through bends and turns in pipe **1820**. In other embodiments, the one or more strain gauges may instead or additionally be disposed around or in a push cable spring, such as push cable spring **1720** of FIG. **17**B, rather than in the push cable **1820** of FIG. **18**. In the various embodiments, the one or more strain gauges, such as strain gauges **1856**, may measure both the degree and direction of movements. The one or more image sensors **1811** may be HDR or auto HDR imagers. An illumination element **1815** may be disposed in camera head **1810** that may be or include LEDs or other light producing elements configured to illuminate the field of view of the one or more image sensors **1811**.

The camera head **1810** may include a processing element **1816** configured to receive video signals **1812** and inertial data **1814** and, in some embodiments, other non-video data from other sensors or elements in the camera head or otherwise directly or indirectly wired or wirelessly coupled system devices. Such non-video data may include datalink signals **1817** which may include instructions from other system devices. In some embodiments, the datalink signal **1817** may include cable counting data from a cable counting element **1842** corresponding to the measured amount of push cable **1820** dispensed from drum reel **1840**. The cable counting element **1842** is illustrated as coupled to the drum reel **1840** in system **1800**. In some system embodiments, a cable counting element such as cable counting element **1842** may be included for measuring the amount of push cable dispensed. Power **1819** may likewise be provided to processing element **1816** for provisioning to the camera head **1810**. For instance, the CCU **1845**, drum reel **1840**, or other connected system device may be battery powered or otherwise connect to a power outlet which may further power the camera head **1810**.

Corrected inertial data and pipe mapping methods, such as method **300** of FIG. **3**, may be performed partially or fully in the processing element **1816** of camera head **1810**. Such corrected inertial data may include inertial data determined via strain gauges **1856**. Such processing may additionally or instead occur in processing elements disposed in the CCU **1845** and/or utility locating device **1860** and/or computing devices **1850** and/or other system devices containing a processing element. Likewise, storage of system data, including video signals and data, inertial data, output of inertial data and pipe mapping methods, and/or other system data may occur in the CCU **1845** and/or utility locating device **1860** and/or computing devices **1850** and/or other system devices containing storage which include one or more non-transitory memories. The processing element **1816** may be configured to receive datalink signals **1817** and perform operations relating to received instructions as well as communicate instructions to the various sensors and other elements of camera head **1810**.

The processing element **1816** may generate output video and non-video data signals **1818** communicated via push cable **1820** to the CCU **1845** and/or utility locating device **1860** and/or computing devices **1850** and/or other system devices. Output video and non-video data signals **1818** may include data relating to video signal **1812** and inertial data **1814**.

Displaying of video/image data may occur at one or more system devices equipped with a display element (e.g., CCU **1845**, utility locating device **1860**, computing devices **1850**, or the like). A wireless link **1880** may allow the exchange of data between the drum reel **1840** and/or CCU **1845** and the utility locating device **1860** as well as the exchange of data between the drum reel **1840** and/or CCU **1845** and one or more other wirelessly connected computing devices **1850**. The computing devices **1850** may be or include smart phones, laptop computers, and/or other like portable or non-portable computing devices **1850**. In some embodiments, such computing devices **1850** may include one or more remote servers.

Turning to FIGS. **19**A and **19**B, the camera head **1910**, which may be or share aspects with the various camera head embodiments disclosed herein further having a push cable spring **1920** couple behind camera head **1910** on end. In assembly, the opposite end of the push cable spring **1920** may couple to a push cable **1925** which, in an inspection system, may further connect to a drum reel and a CCU such as the drum reel **2140** and CCU **2145** of system **2100** of FIG. **21**. In the assembly of FIGS. **19**A and **19**B, the push cable spring **1920** may be used to further improve movement and/or handling of the camera head **1910** into and inside a pipe or other void. An optical lace system **1930** may be disposed in the push cable spring **1920**. The optical lace system **1930** may estimate the configuration of the push cable spring **1920** (or length of push cable **1925** in some alternative embodiments) as the assembly moves through bends and turns in the pipe or other conduit. For instance, the optical lace system **1930** may include a deformable lattice structure embedded with optical fibers or similar optical pathways to interpret the movement of light via a series of sensors in order to determine the degree, direction, and location of deformation movements along the lattice structure. In use with a pipe inspection system, as an assembly containing the optical lace system is moved through bends and turns in a pipe or other conduit resulting deformation movements in the lattice structure may be interpreted, in both degree and direction, and mapped as movements of the camera head at a known distance from the optical lace system. Such inertial data generated via the optical lace system **1930** may further be communicated to one or more processing elements in the camera head **1910** and/or a CCU and/or other coupled or wirelessly connected system devices. In some embodiments, an optical lace system, such as optical lace system **1930**, may instead or additionally be disposed around or in a length of push cable **1925**. In some embodiments, the push cable spring **1920** and/or lattice structure of the optical lace system **1930** may be 3D printed.

Turning to FIG. **20**, a camera head **2010**, which may be or share aspects with the various camera head embodiments disclosed herein, is further illustrated having an optical lace system **2030** that may further function as a push cable spring to provide improved movement and/or handling control of a camera head **2010** into and inside a pipe or other void. The optical lace system **2030** may couple behind camera head **2010** on the end and couple to a push cable **2025** on the opposite end. In an inspection system, the push cable **2025** may further connect to a drum reel and a CCU such as the drum reel **2140** and CCU **2145** of system **2100** of FIG. **21**. The optical lace system **2030** may, beyond generating inertial data corresponding to degree and direction of movement of the camera head as moved through bend and turns in a pipe or other conduit, may have various sections of differing stiffness, such as optical lace sections **2032**, **2034**, and **2036**, allowing for improved control and handling of the assembly. For instance, optical lace section **2036** may be the least stiff allowing the camera head **2010** to more easily be moved along bends and turns. The remaining optical lace sections **2034** and **2032** may be increasingly more stiff to better match the stiffness of the push cable **2025** and allow the assembly to otherwise more readily be moved into and through a pipe or like conduit. In some embodiments, the lattice structure of the optical lace system **2030** may be 3D printed. In some embodiments, a push cable spring, such as the push cable spring **1920** of FIGS. **19**A and **19**B, may itself contain optical fibers or similar optical pathways further coupled to one or more illumination sources and optical sensors in order to determine the degree and direction bending movements of the push cable spring.

A diagram of a pipe inspection and mapping system embodiment **2100** which may include an optical lace system (e.g., optical lace **2156**) is illustrated in FIG. **21**. In system **2100**, a camera head **2110** may include one or image sensors **2111** generating video signal(s) **2112** which may be video and images of scenes from the inside of pipe **2125** and one or more inertial and/or other camera head movement measuring sensor(s) **2113** generating inertial data **2114** relating to measured positions, orientations, and movements (or lack thereof) of the camera head **2110**. The inertial sensor(s) and/or other camera head movement measuring sensor(s) **2113** may include accelerometers, magnetometers, gyroscopic sensors, and/or other sensor for or relating to measuring positions, orientations, and movements (or lack thereof) of the camera head **2110**. The inertial sensor(s) and/or other camera head movement measuring sensor(s) **2113** may be nine-axis sensors, six-axis sensors, or other sensors measuring along any number axes or combination of sensors measuring along different axes. Such inertial data may further include movements estimating the configuration of a push cable **2120** coupled to camera head **2110** via optical lace **2156** as the assembly is moved through bends and turns in pipe **2120**. In other embodiments, the optical lace may instead or additionally be disposed around or in a push cable spring, such as push cable spring **1720** of FIG. **17**B, and/or be the push cable spring mechanism in providing improved handling of the assembly as described with the optical lace system **2030** of FIG. **20**. In the various embodiments, the optical lace system, such as optical lace **2156**, may measure both the degree and direction of bending movements as the assembly is moved through bends and turns.

The one or more image sensors **2111** may be HDR or auto HDR imagers. An illumination element **2115** may be disposed in camera head **2110** that may be or include LEDs or other light producing elements configured to illuminate the field of view of the one or more image sensors **2111**.

The camera head **2110** may include a processing element **2116** configured to receive video signals **2112** and inertial data **2114** and, in some embodiments, other non-video data from other sensors or elements in the camera head or otherwise directly or indirectly wired or wirelessly coupled system devices. Such non-video data may include datalink signals **2117** which may include instructions from other system devices. In some embodiments, the datalink signal **2117** may include cable counting data from a cable counting element **2142** corresponding to the measured amount of push cable **2120** dispensed from drum reel **2140**. The cable counting element **2142** is illustrated as coupled to the drum reel **2140** in system **2100**. In some system embodiments, a cable counting element such as cable counting element **2142** may be included for measuring the amount of push cable dispensed. Power **2119** may likewise be provided to processing element **2116** for provisioning to the camera head **2110**. For instance, the CCU **2145**, drum reel **2140**, or other connected system device may be battery powered or otherwise connect to a power outlet which may further power the camera head **2110**.

Corrected inertial data and pipe mapping methods, such as method **300** of FIG. **3**, may be performed partially or fully in the processing element **2116** of camera head **2110**. Such corrected inertial data may include inertial data determined via optical lace **2156**. Such processing may additionally or instead occur in processing elements disposed in the CCU **2145** and/or utility locating device **2160** and/or computing devices **2150** and/or other system devices containing a processing element. Likewise, storage of system data, including video signals and data, inertial data, output of inertial data and pipe mapping methods, and/or other system data may occur in the CCU **2145** and/or utility locating device **2160** and/or computing devices **2150** and/or other system devices containing storage which include one or more non-transitory memories. The processing element **2116** may be configured to receive datalink signals **2117** and perform operations relating to received instructions as well as communicate instructions to the various sensors and other elements of camera head **2110**.

The processing element **2116** may generate output video and non-video data signals **2118** communicated via push cable **2120** to the CCU **2145** and/or utility locating device **2160** and/or computing devices **2150** and/or other system devices. Output video and non-video data signals **2118** may include data relating to video signal **2112** and inertial data **2114**.

Displaying of video/image data may occur at one or more system devices equipped with a display element (e.g., CCU **2145**, utility locating device **2160**, computing devices **2150**, or the like). A wireless link **2180** may allow the exchange of data between the drum reel **2140** and/or CCU **2145** and the utility locating device **2160** as well as the exchange of data between the drum reel **2140** and/or CCU **2145** and one or more other wirelessly connected computing devices **2150**. The computing devices **2150** may be or include smart phones, laptop computers, and/or other like portable or non-portable computing devices **2150**. In some embodiments, such computing devices **2150** may include one or more remote servers.

Turning to FIGS. **22**A-**22**C, a camera head **2210**, which may be or share aspects with the various camera head embodiments disclosed herein including a push cable spring **2220** coupled behind camera head **2210** and between the camera head **2210** and a push cable **2225**. A termination **2226** may couple the push cable **2225** and push cable spring **2220**. The push cable spring **2220** may be used to further improve movement and/or handling of the camera head **2210** into and inside a pipe or other void.

As illustrated in FIGS. **22**B and **22**C, one or more inertial sensors **2228** which may be or include magnetometers, gyroscopic sensors, accelerometers, and/or other motion or motion related sensors may be disposed in the termination **2226**. In other embodiments, inertial sensors may likewise or instead be included in or on push cable **2225** and/or push cable spring **2220** in a known orientation relative to the inertial sensors **2212** in the camera head **2210**. The inertial sensor **2212** may be or include magnetometers, gyroscopic sensors, accelerometers, and/or other motion or motion related sensors and/or be the nine axis sensors described in the various embodiments herein. The inertial sensors **2210** and **2228** may transmit their output to processing elements disposed in the camera head **2210** and/or a CCU and/or other coupled or wirelessly connected system devices to estimate and map the degree and direction of bends and turns in a pipe or other conduit as the assembly is made to move through. For instance, inertial sensors **2210** and **2228** may have a known alignment relative to one another as illustrated in FIG. **22**B. When a change in alignment has occurred, as illustrated in FIG. **22**C, the amount of difference may be measured and used to determine the degree and direction of the bend or turn experience and further mapped via the camera head **2210**. A measure of the change of alignment between inertial sensors **2210** and **2228** may, for instance, utilize lookup tables or other indexing operations and/or various other computational methods to determine the degree and direction of the bend or turn experience and mapped via the camera head **2210**.

Still referring to FIGS. **22**B and **22**C, the assembly may further include one or more magnets, such as magnet **2230**, disposed in a known location relative to the one or more inertial sensors **2210** and/or **2228** which may be or include magnetometers. The orientation of the polarity of magnet **2230** may be known such that when a bend or turning movement occurs at the assembly, the degree and direction of the bend or turn may be determined via change in alignment and distance between magnet **2230** and the one or more inertial sensors **2210** and **2228**. In some such embodiments, the magnet **2230** may be cylindrical, toroidal, or some other shape. Likewise, such an embodiment may include more than one magnet which may also be located in the camera head **2210**, in or near the push cable spring **2220**, push cable **2225**, and/or termination **2226**.

A diagram of a pipe inspection and mapping system embodiment **2300** which may include multiple inertial sensors, magnetometers, and/or like sensors with known orientations in different locations to determine bends and turns in pipes (e.g., inertial sensor(s)/magnetometer(s) **2356** and inertial sensor(s) and/or other camera head movement measuring sensor(s) **2313**) is illustrated in FIG. **23**. In such a system as pipe inspection and mapping system embodiment **2300**, the degree and direction of misalignment between such sensors (e.g., inertial sensor(s)/magnetometer(s) **2356** and inertial sensor(s) and/or other camera head movement measuring sensor(s) **2313**) may allow for the degree and direction of bends in a pipe to be determined and mapped. In some such systems as pipe inspection and mapping system embodiment **2300**, one or more magnets, such as magnet **2357**, may be disposed along push cable **2320** or otherwise in a location relative to the one or more sensors (e.g., inertial sensor(s)/magnetometer(s) **2356** and inertial sensor(s) and/or other camera head movement measuring sensor(s) **2313**). The orientation of the magnet's **2230** polarity may be known such that when a bend or turning movement occurs at the assembly, the degree and direction of the bend or turn may be determined via change in alignment and distance to between magnet **2230** and the one or more sensors. In some such embodiments, the magnet **2230** may be cylindrical, toroidal, or some other shape. Likewise, such an embodiment may include more than one magnet which may also be located in the camera head **2210**, in or near the push cable spring **2220**, push cable.

In system **2300**, a camera head **2310** may include one or image sensors **2311** generating video signal(s) **2312** which may be video and images of scenes from the inside of pipe **2325** and one or more inertial sensor(s) and/or other camera head movement measuring sensor(s) **2313** generating inertial data **2314** relating to measured positions, orientations, and movements (or lack thereof) of the camera head **2310**. The inertial sensor(s) and/or other camera head movement measuring sensor(s) **2313** may include accelerometers, magnetometers, gyroscopic sensors, and/or other sensors for or relating to measuring positions, orientations, and movements (or lack thereof) of the camera head **2310**. Such inertial data may further include movements estimating the bending configurations of a push cable **2320** coupled to camera head **2310** via a measured difference in alignment between the inertial sensor(s) and/or other camera head movement measuring sensor(s) **2313** and one or more additional inertial sensors/magnetometer(s) **2356** in or around push cable **2320** that may be generated as the assembly is moved through bends and turns in pipe **2320**. In other embodiments, the inertial sensors may instead or additionally be disposed around or in a push cable spring, such as push cable spring **1720** of FIG. **17**B, and/or a termination such as termination **2226** of FIGS. **22**A-**22**C.

The one or more image sensors **2311** of camera head **2310** may be HDR or auto HDR imagers. An illumination element **2315** may be disposed in camera head **2310** that may be or include LEDs or other light producing elements configured to illuminate the field of view of the one or more image sensors **2311**.

The camera head **2310** may include a processing element **2316** configured to receive video signals **2312** and inertial data **2314** and, in some embodiments, other non-video data from other sensors or elements in the camera head or otherwise directly or indirectly wired or wirelessly coupled system devices. Such non-video data may include datalink signals **2317** which may include instructions from other system devices. In some embodiments, the datalink signal **2317** may include cable counting data from a cable counting element **2342** corresponding to the measured amount of push cable **2320** dispensed from drum reel **2340**. The cable counting element **2342** is illustrated as coupled to the drum reel **2340** in system **2300**. In some system embodiments, a cable counting element such as cable counting element **2342** may be included for measuring the amount of push cable dispensed. Power **2319** may likewise be provided to processing element **2316** for provisioning to the camera head **2310**. For instance, the CCU **2345**, drum reel **2340**, or other connected system device may be battery powered or otherwise connect to a power outlet which may further power the camera head **2310**.

Corrected inertial data and pipe mapping methods, such as method **300** of FIG. **3**, may be performed partially or fully in the processing element **2316** of camera head **2310**. Such corrected inertial data may include inertial data determined via differences in inertial sensors such as inertial sensors/magnetometer(s) **2356** and inertial sensor(s) and/or other camera head movement measuring sensor(s) **2313**. Such processing may additionally or instead occur in processing elements disposed in the CCU **2345** and/or utility locating device **2360** and/or computing devices **2350** and/or other system devices containing a processing element. Likewise, storage of system data, including video signals and data, inertial data, output of inertial data and pipe mapping methods, and/or other system data may occur in the CCU **2345** and/or utility locating device **2360** and/or computing devices **2350** and/or other system devices containing storage which include one or more non-transitory memories. The processing element **2316** may be configured to receive datalink signals **2317** and perform operations relating to received instructions as well as communicate instructions to the various sensors and other elements of camera head **2310**.

The processing element **2316** may generate output video and non-video data signals **2318** communicated via push cable **2320** to the CCU **2345** and/or utility locating device **2360** and/or computing devices **2350** and/or other system devices. Output video and non-video data signals **2318** may include data relating to video signal **2312** and inertial data **2314**.

Displaying of video/image data may occur at one or more system devices equipped with a display element (e.g., CCU **2345**, utility locating device **2360**, computing devices **2350**, or the like). A wireless link **2380** may allow the exchange of data between the drum reel **2340** and/or CCU **2345** and the utility locating device **2360** as well as the exchange of data between the drum reel **2340** and/or CCU **2345** and one or more other wirelessly connected computing devices **2350**. The computing devices **2350** may be or include smart phones, laptop computers, and/or other like portable or non-portable computing devices **2350**. In some embodiments, such computing devices **2350** may include one or more remote servers.

Turning to FIG. **24**, a method **2400** for generating corrected inertial data and a subsequent pipe map is described. In a step **2410**, the pipe inspection operation may begin. In a step **2420**, the initial location of the camera head into a pipe and heading or orientation may be determined. Step **2420** may, for instance, include the use of magnetometers in the camera head to determine heading/orientation. In a step **2430**, the camera head may be moved in a pipe. In a step **2440**, movement data relating to the camera head may be determined and stored. For instance, inertial data relating to movement of the camera head may be determined via a push cable counter, various inertial sensors (including redundant inertial sensors at different system location configured to measure bending movements), strain gauges, optical lace systems, and/or other like sensors or systems. In an optional step **2450**, the inertial data may be correlated and corrected to push cable count data (e.g., through method **300** of FIG. **3**). In a step **2460**, a pipe map may be generated based on inertial data correlating to pipe inspection imager and other non-video data.

Turning to FIG. **25**, the camera head embodiments described herein may use a method **2500** to control on and off automatic white balance (AWB). In a step **2510**, the inspection system may be turned on wherein the AWB is set to a first AWB setting. The first AWB setting may be on and optimized for the environment outside of a pipe allowing the camera to clearly view the environment outside the pipe. In a step **2520**, the pipe inspection system reaches a configured parameter limit relating to the AWB of the camera head image sensors. For instance, the configured parameter limit may be a certain time from startup (generally long enough for the camera head to have entered the pipe), a certain push cable count provided by a cable counter element, a level of movement detected by the inertial sensors and/or image sensors, or other parameter allowing the outside of the pipe to be viewed with optimized AWB and for AWB to be turned off or down to optimize viewing inside of a pipe. In a step **2530**, the inspection system may switch to a second AWB setting. The second AWB setting may, for instance, turn AWB off completely or turn the sensitivity down. The various AWB settings may be configured to match the camera heads LED light output, stored in memory on the camera head and/or CCU and/or other coupled or remotely connected system devices. In some embodiments, the second AWB setting may further be determined by color sensors in the camera head adjustably defined according to a look up table which may use time and temperature as variables that may be measured by sensors disposed in the camera head.

In one or more exemplary embodiments, certain functions, methods and processes described herein related to control of and/or data communication to or from imaging modules, illumination modules, processing elements, and/or other electronic elements of camera heads and associated inspection systems may be implemented in hardware, software, firmware or any combination thereof. If implemented in software, the functions may be stored on or encoded as one or more instructions or code on a non-transitory computer-readable medium. Computer-readable media includes computer storage media. Storage media may be any available media that can be accessed by a computer. By way of example, and not limitation, such computer-readable media can include RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code in the form of instructions or data structures and that can be accessed by a computer. Disk and disc, as used herein, include compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and Blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media.

It is understood that the specific order or hierarchy of steps or stages in the processes and methods disclosed herein are examples of exemplary approaches. Based upon design preferences, it is understood that the specific order or hierarchy of steps or stages in the processes may be rearranged while remaining within the scope of the present disclosure. Any accompanying method claims present elements of the various steps in a sample order and are not meant to be limited to the specific order or hierarchy presented unless explicitly noted.

Those of skill in the art would understand that information and signals may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles or any combination thereof.

Those of skill would further appreciate that the various illustrative logical blocks, modules, circuits and algorithm steps described in connection with the embodiments disclosed herein may be implemented as electronic hardware, computer software or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the disclosure.

The various illustrative logical blocks, modules, and circuits described in connection with the embodiments disclosed herein and, for example, in processing elements as described herein may be implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration. A processing element may further include or be coupled to one or more memory elements for storing instructions, data and/or other information in a non-transitory digital storage format.

The steps or stages of a method, process or algorithm described in connection with the embodiments disclosed herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module may reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, CD-ROMs or any other form of storage medium known or developed in the art. An exemplary storage medium is coupled to the processor such that the processor can read information from and write information to the storage medium. In the alternative, the storage medium may be integral to the processor. The processor and the storage medium may reside in an ASIC. The ASIC may reside in a user terminal. In the alternative, the processor and the storage medium may reside as discrete components in a user terminal.

The scope of the disclosure is not intended to be limited to the aspects shown herein, but is to be accorded the full scope consistent with the language of this specification and accompanying drawings, wherein reference to an element in the singular is not intended to mean "one and only one" unless specifically so stated, but rather "one or more." Unless specifically stated otherwise, the term "some" refers to one or more. A phrase referring to "at least one of" a list of items refers to any combination of those items, including single members. As an example, "at least one of: a, b, or c" is intended to cover: a; b; c; a and b; a and c; b and c; and a, b and c.

The previous description of the disclosed aspects is provided to enable any person skilled in the art to make or use embodiments of the present invention. Various modifications to these aspects will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other aspects without departing from the spirit or scope of the invention. Thus, the scope of the invention is not intended to be limited to the aspects shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

We claim:

1. A system for inspecting and/or mapping pipes or cavities, comprising:

a cable storage drum;

a push-cable, retractably stored inside the cable storage drum, having a distal end and a proximal end;

a camera head, coupled to the distal end of the push-cable, comprising one or more image sensors to capture images and/or videos from interior of a pipe or cavity, the camera head movable in a first direction when the push-cable is deployed into the pipe or cavity and a second direction, different from the first direction, when the push-cable is retracted from the pipe or cavity;

one or more multi-axis inertial sensors disposed in the camera head to sense inertial data corresponding to movement of the camera head in the first direction and the second direction; and

a processing element communicatively coupled to the image sensors and the inertial sensors to receive the images and/or videos from the image sensors and the sensed inertial data from the inertial sensors; and generate, based at least on the received images and/or videos and the inertial data sensed during movement of the camera head in the first direction and the second direction, information pertaining to the pipe or cavity.

2. The system of claim **1**, further comprising a cable counter to generate cable count data indicative of an amount of cable dispensed or retracted to/from the cable storage drum.

3. The system of claim **2**, wherein the generated information pertaining to the pipe or cavity is further based on the cable count data.

4. The system of claim **2**, wherein the processing element correlates, based at least on the cable count data, the inertial data sensed in the first direction and the second direction and associates the images and/or videos of the pipe or cavity with the correlated data to generate a pipe map, wherein one or more location points on the pipe map corresponds to location points on a ground surface.

5. The system of claim **1**, further comprising one or more buried utility locator devices to receive electromagnetic field signals emitted from a hidden or buried pipe or cavity and determine, based at least on the received electromagnetic field signals, location or position of the hidden or buried pipe or cavity.

6. The system of claim **1**, further comprising one or more electronic devices communicatively coupled to the processing element to display and/or store the images and/or videos representing interior of the pipe or cavity.

7. The system of claim **6**, further comprising a wireless transceiver module to wirelessly transmit the images and/or videos and/or inertial data for processing, storage, and/or display onto the one or more coupled electronic devices.

8. The system of claim **7**, wherein the wireless transceiver module is disposed in a central hub of the cable storage drum.

9. The system of claim **1**, wherein the camera head is a self-leveling camera head.

10. The system of claim **1**, wherein the image sensors are high dynamic range (HDR) sensors.

11. The system of claim **1**, wherein the one or more multi-axis inertial sensor comprises at least a nine-axis sensor including a three-axis accelerometer, a three-axis magnetometer and a three-axis gyroscope.

12. The system of claim **1**, further including one or more acoustic exciter devices to broadcast acoustics signal in locations by the pipe being inspected.

13. The system of claim **1**, including a push cable spring disposed behind the camera head that includes one or more strain gauges.

14. The system of claim **1**, including a push cable spring disposed behind the camera head that includes an optical lace system configured to determine deformations in the lace network through changes in optical patterns coinciding with camera head movements in the pipe.

15. The system of claim **1**, wherein the push cable spring is 3D printed.

16. The system of claim **1**, wherein the push cable spring is an optical lace system.

17. The system of claim **16**, wherein the optical lace system push cable spring includes a plurality of sections having various sections of differing stiffnesses.

18. The system of claim **16**, wherein the camera head, push cable, and push spring assembly includes a series of spatially separated magnetometers or other inertial sensors having known orientations and the degree and direction of bends and turns in the pipe are measured and mapped at least in part based on changes in the alignment of the sensors.

19. The assembly of claim **18**, further including one or more magnets having a known location or polarity orientation relative to the magnetometers/inertial sensors such that the degree and direction of bends and turns in the pipe are measured and mapped based at least in part on changes in the alignment between the magnets and sensors.

20. The assembly of claim **19**, wherein the one or more magnets have a toroidal shape.

21. The assembly of claim **19**, wherein the one or more magnets have a cylindrical shape.

22. The system of claim **1**, including a Sonde device to broadcast a signal capable of being modulated.

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